THE JOURNAL of the Acoustical Society of America

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THE JOURNAL
of the Acoustical Society of America

Volume II Number 1

JULY · 1930

PROGRAM OF THE THIRD MEETING
OF THE
ACOUSTICAL SOCIETY OF AMERICA

MAY, 9 AND 10, 1930

Westinghouse Lighting Institute Auditorium
Grand Central Palace
Lexington Avenue at 47th Street
New York City

FRIDAY, MAY 9TH
9:30 A. M.

SYMPOSIUM ON NOISE

1. **Introductory Remarks—N. Y. City's Noise Abatement Commission,** DR. SHIRLEY WYNNE, *Health Commissioner*, N. Y. C. (10 minutes).

2. **Summary of Previous and Existing Methods of Noise Measurement,** DR. E. E. FREE, (30 minutes).

Previous methods of noise measurement by reasonators, oscillographs, the Rayleigh disc, the audiometer and others will be reviewed critically. Modern methods using vacuum tube amplifiers will be described. The outstanding problem of noise measurement at present is the rapid and accurate evaluation of the frequency spectrogram. One phase of this is the perfection of a noise meter agreeing in frequency characteristics with the average ear. Researches now in progress along these lines will be described and illustrated.

3. **Results of Noise Surveys** (40 minutes).

Part I. Noise Out-of-Doors—ROGERS H. GALT, *Bell Telephone Laboratories.*

II. Noise in Buildings—REXFORD S. TUCKER, *American Telephone and Telegraph Co.*

III. Noise Reduction—JOHN PARKINSON, *Johns-Manville Corp.*

A summary is given of the results of noise surveys, including new measurements as well as certain material previously available. The report treats of noise out-of-doors, in buildings and in conveyances, and discusses noise levels and characteristics, noise sources, and noise reduction.

4. The Objective Measurement of Machinery Noises—F. A. FIRESTONE, *University of Michigan*, (30 minutes).

The accurate measurement of the intensity of machinery noises, especially those of musical character, is very difficult under ordinary conditions on account of the presence of the interference pattern. The sound chamber method has been adapted to this problem, using a rotating reflector for securing uniform average distribution of sound intensity. A condenser microphone with tuned amplifier and slowly responding indicating meter is used for making the measurements which can be repeated on the same day with an accuracy of 0.5 decibel. In place of the tuned circuit in the amplifier, a "loudness circuit" is sometimes used which weights the various frequencies according to the sensitivity of the average ear at a loudness level 60 db. above the 700 cycle threshold. The loudness readings of six vacuum cleaners as taken with this apparatus checked against the average loudness estimate of twenty observers.

5. Elimination of Noise in Machinery—ARTHUR L. KIMBALL, *General Electric Co.*, (30 minutes).

Direct and indirect noise.
Three ways of treating problems:
(1) Elimination at source.
(2) Screening.
(3) Elastic Suspension.
Brief discussion of these with illustrations.
Remarks on theory of elastic suspension.
Further illustrations from practice.

12:30 P. M. to 2:00
LUNCHEON

FRIDAY, MAY 9TH
2:00 P. M.

1. A Concatenated Cone Speaker which Behaves Essentially as a Point Source, A. V. BEDFORD, *Research Laboratory, General Electric Co.*

It is evident that if a speaker is to show great fidelity of reproduction of sound in all directions from the speaker, it must generate the *same* shaped waves for all frequencies. The generation of plane waves would require for the lower frequencies, a uniformly driven surface very much larger than is considered practicable for general use. (Dr. Hewlett's speaker is a good one of this type.)

The simplest means of generating a spherical wave apparently would be to use a piston whose diameter is smaller than the wave length of the highest frequency sound wave to be generated. However, a piston which is small enough to fill this requirement on 5000 cycles per second would have to move an absurdly great distance (several inches) at the lower audio frequencies to produce sufficient sound.

The present paper discusses and gives the results of tests on a new multiple cone structure speaker which changes its effective size so that it is practically a point source for all frequencies.

The transition from one effective size to another is made smoothly and in such a way that no major variations in response occur due to either interference or resonance.

2. The Binaural Localization of Pure Tones, E. R. WIGHTMAN and F. A. FIRESTONE, *University of Michigan.*

Measurements of phase difference and amplitude ratio of the sound entering the ears of a man-shaped wax dummy were taken with the source at varying azimuths around the head; at 256, 1024 and 1944 cycles per second; and at distances of 20, 50, 100 and 400 cm. from the head. The measurements at the two frequencies agree with the values published by Hartley and Fry computed on the assumption that the head is a rigid sphere in free space, except that the observed values of amplitude ratio are about 13 per cent. less than the computed values on account of the interference of the neck. The observed values at 1944 cycles are quite different from the computed values.

As a converse experiment, pure tones of frequency 256 cycles were presented binaurally to eight different observers, the phase difference and amplitude ratio of the acoustical pressures at the two ears being known and adjustable. The observers were asked to state the direction and distance of the apparent source of sound. Only three of the eight observers were influenced in their judgment of direction by the phase difference and even they were rather inaccurate. All were influenced more or less in judging direction by the amplitude ratio. None was able to tell the distance of the source by the amplitude ratio.

3. Some High Scale Acoustic Phenomena, R. B. BOURNE, *The Maxim Silencer Company.*

A definition of "high scale" is given. Various phenomena encountered in the field are described, together with certain psychological considerations. Physical factors influencing silencer design are discussed. The Maxim Gun Silencer is described and demonstrated.

4. Some New Instruments in the Iowa Laboratory for the Psychology of Music, C. E. SEASHORE, *University of Iowa.*

This is a report describing briefly the following new instruments developed by the staff in the University of Iowa.

1. Piano camera: a camera which records the time and the force of the stroke for the entire keyboard in piano playing, under normal conditions of playing. (Tiffin and Seashore.)
2. Certain modifications of Metfessel's strobophotographic camera which graphs pitch and time of a solo instrument or voice, photographically. (Reger and Tiffin.)
3. The new synthetic vibrato apparatus: utilizes the photoelectric cell in controlling all the factors in the vibrato. (Tiffin.)
4. The rhythm meter: a graphic method of measuring precision in rhythm performance. (Seashore, C. E. and R. H.)
5. The tone dynometer: a means of measuring precision in musical "touch." (Seashore.)

6. A new model of the tonoscope: portable and adaptable for general laboratory and studio use. (Seashore and Williams.)

5. The Reverberation Time Bridge—An Instrumental Method for Measuring Reverberation Time, HARRY F. OLSON and BARTON KREUZER, *RCA Photophone, Inc.*

The analogy between the decay of the electrical energy in a capacitor shunted by a resistor and the decay of sound energy in a room with sound absorbing walls is the basis of this bridge.

The sound pressure is converted into a corresponding electrical voltage by a microphone and amplifier. This voltage is measured by a linear type v.t. voltmeter. The voltage across the resistor shunting the capacitor is measured by another similar v.t. voltmeter.

The room and capacitor are "charged" until steady state conditions are established, the capacitor charging voltage and the sound source are then cut off simultaneously. The bridge is balanced by adjustment of the variable discharge resistor, until the two voltages are equal during the decay period.

The value of "t" in the "time constant" of the electrical circuit is then the actual reverberation time.

6. Incommensurability of the Octave Interval with any other Interval, WILMER T. BARTHOLOMEW, *Peabody Conservatory of Music.*

Although it is common knowledge that the well-known tempered scale of twelve semitones is s tnesimperfect, relatively few musicians understand the necessary cause of that imperfection, which lies in the mathematical relations of the ratios involved.

In any method of tuning, the ear demands that at least the octaves must be true. It is demonstrated that if this is so, no other true interval, if successively stepped off from a tarting tone, can ever arrive at an exact octave of the starting tone.

The mathematics, though elementary and obvious to the scientific musician, is important ince *it* underlies all attempts at tempering scales.

7. The Two Points of View in Teaching the Control of the Human Voice in Speech and Song, LOUIS SIMMIONS.

First: The School of the control of the vowels. This includes the teaching of the Bell Canto. The *Old Italian School* where the human voice is treated purely as an instrument where beautiful sound predominates.

Second: The Consonantal School of dramatic recitation in speech and in song where beautiful sound in voice development is not a prime consideration. This school belongs to the *German and French.*

The speaker, through practical demonstration, believes he can prove that the constant struggle between these two schools can be eliminated and coordinated through scientific investigation of the action of the *Ventricles of Morgagni*—two air spaces situated in the throat between the true and false vocal chords. According to some authorities and the speaker's own investigation these two ventricles or air pockets act as a valve and control the air pressure above the oscillation of the vocal chords, consequently controlling the binding of the two elements in speech and in song.

SATURDAY, MAY 10TH
9:30 A. M.

SYMPOSIUM ON LOUD SPEAKERS

1. **I. Theory of the Electrostatic Loud Speaker,** C. R. HANNA, *Westinghouse Electric & Mfg. Co.* (20 minutes).

In the electromagnetic driver the force per unit current has been shown to be a function of the inductance and the negative stiffness resulting from the presence of the steady magnetic field. In this paper it is proven that the force per unit voltage in the electrostatic device is a similar function of the capacity and the negative stiffness due to the steady electrostatic field.

A new concept called Motional Admittance is introduced for the electrostatic loud speaker and this is shown to be similar in its mathematical form to the Motional Impedance of the electromagnetic driver.

A calculation of the ultimate theoretical efficiency that may be obtained with an electrostatic speaker having a pure resistance radiator and covering a given frequency range is given. It appears that efficiencies between 5 and 10% may some day be obtainable with good fidelity of reproduction.

II. Theory of the Horn Type Loud Speaker, C. R. HANNA, *Westinghouse Electric & Mfg. Co.*, (20 minutes).

2. **Directed Radiation of Sound from Loud Speakers,** IRVING WOLFF, *RCA-Victor Co., Inc.*, and LOUIS MALTER, *RCA-Photophone* (30 minutes).

A discussion of the importance of the directional characteristics of loud speakers from the standpoint of good reproduction of sound in small rooms and auditoriums. Calculated results will be shown for a number of ideal sound radiators and experimental measurements will be given in a number of typical cases.

3. **Loud Speaker Sound Pressure Measurements,** EDWARD W. KELLOGG, *RCA-Victor Co.*, (30 minutes).

Methods of taking frequency-response curves of loud speakers have tended to become prematurely standardized within commercial organizations, and inadequately standardized in the industry as a whole. Characteristics taken by different experimenters are not comparable. Each may have a good defense to make of his system, and it is the writer's plea that such discussion should be "A free for all, and not a private affair." More general discussion would promote education if not standardization. A critical attitude on the part of all is desirable, and a demand that published curves be accompanied by information as to method of test.

Two valuable contributions on the subject have so far been published, in which the result obtained by several methods of test are compared. This paper makes additional contribution to the experimental evidence, suggests some other methods of measurement, and criticises the several methods from a theoretical standpoint. One of the difficulties arises from the fact that it is desired to show a single curve whose flatness is an indication of the general merit or fidelity of the loud speaker, whereas the differences in directive properties as well as in total sound output make it impossible to describe the properties of a speaker in a single curve. Only in as far as it is possible to specify the exact conditions under which the loud speaker will be used, can such a single curve have significance.

4. An Efficient Loud Speaker at the Higher Audible Frequencies, L. G. BOSTWICK, *Bell Telephone Laboratories.* (30 minutes).

This paper describes a loud speaker designed for use as an adjunct to existing types for the purpose of extending the range of efficient performance to 11,000 or 12,000 cycles. A moving coil piston diaphragm structure is used in conjunction with a 2000 cycle cut-off exponential horn having a mouth diameter of about 2 inches. Motional impedance measurements on this loud speaker indicate an average absolute efficiency of about 20% within the frequency range from 3000 to 11,000 cycles. The variation in response within this band does not exceed 5 db. By using a high frequency loud speaker of this type the efficiency and power capacity of the associated low frequency loud speaker can be improved and a uniform response-frequency curve from 50 to 12,000 cycles can be obtained.

12:30 P. M. to 2:00 P. M.
LUNCHEON

SATURDAY, MAY 10TH,
2:00 P. M.

1. Masking Effects of an Interfering Tone Upon a Deafened Ear, JOHN GUTTMAN, *N. Y. Post Graduate Hospital* and L. B. HAM, *N. Y. University.*

These experiments were made to test the masking function of deafened ears by means of two tones. The threshold intensity of the person examined is obtained for the one tone and then this intensity is increased 50 decibels. This tone we have called the interfering tone. The threshold intensity of the other tone (i.e., the primary) is found with and without the interfering tone. The difference between the two threshold intensity values of the primary tone is called the differential threshold.

We have found the differential threshold to be smaller for deafened people than for normal people. The greater the deafness in the primary tone, the smaller the differential threshold. These findings were found for both the so-called conduction as well as perception deafness. In conduction deafness the effect may be a little more pronounced.

An analysis of the results, especially for the more deafened cases, indicates a supplementary explanation to Paracusis phenomena.

An explanation of the results is given, based upon the supposition of a very sensitive mechanism for damping the transmission of strong sounds. This mechanism acts by reflex action of the cochlea nerve and the nerves supplying the intra-auricular muscles.

2. The Amount and Type of Auditory Stimuli Which Influence Stomach Contractions (*Introduced by* DONALD A. LAIRD). E. L. SMITH, *Colgate University.*

A scientific explanation is needed to account for the observed ill effects of noise on health and efficiency. The hypothesis that noise causes fear reaction has been advanced to give such an explanation. This paper will report experimental observations of changes in stomach tonus, which has been shown to be an aspect of the fear reaction, under various acoustic stimuli. Human beings were experimented on and records of stomach tonus obtained from balloons in the stomach.

3. The Effect of Noise Intensity and Pattern on Locating Sounds (*Introduced by* DONALD A. LAIRD). W. G. KING, *Colgate University.*

A sound cage with a seconds pendulum regulating the intervals between stimuli was used to determine the threshold of two-point discrimination of the position of sound. Observations will be reported on the change in threshold with change in decibel level and absorption in the test chamber, the intensity and character of the discriminated stimulus remaining constant. Bearings of the data on annoyance, fear reaction, and "third dimensional sound" will be pointed out.

4. Acoustics of Lincoln Hall Theater at the University of Illinois, F. R. WATSON, *University of Illinois.*

Recent theory* indicates that perfect acoustics in an auditorium may be obtained by observing conditions leading first, to the perfect generation of sound, and second to the perfect reception of sound. In the generation of sound, it is of great advantage to place reflecting surfaces near the performer to allow him to "hear himself" and thus adjust his sound for best effect. For perfect listening, it appears desirable to reduce as far as possible all reflection of sound about the auditors, since practically all the defects of echoes, reverberation and articulations may be traced to this reflection.

Opportunity to test this theory was given in the construction of a small theater at the University. A huge cyclorama on the stage gave the reflecting surface for performers, while upholstered seats and a very absorbent ceiling treatment reduced reflection for auditors. The acoustic outcome is good.

* *Ideal Auditorium Acoustics, by F. R. Watson, Jour. Amer. Inst. Architects, July, 1928.*

5. Are Acoustical Materials a Menace in the Hospital? CHARLES F. NEERGAARD.

Hospitals must be made quiet. To determine what would best meet their exacting requirements as to cleanliness, maintenance, permanance and cost, a series of tests were undertaken on the various acoustical treatments available. To determine further whether these materials would act as abiding and breeding places for bacteria and so present a menace in hospital construction, experiments were carried out at the bacteriological laboratories of Yale University on three felt materials, Celotex, and an acoustical plaster. A culture of B. prodigiosus, an easily recognizable organism, was first brushed, then sprayed on, and the materials examined microscopically every 48 hours or so, at the surface and three different depths. The results of the two methods of application were almost identical, and varied very little for the five materials. After two days in only the outer layers were bacteria found and after eight days they had disappeared entirely. The tests were made under severe conditions and ordinarily bacteria could probably not penetrate so deeply. It would appear that acoustical materials presented no greater menace than the structural surfaces they would replace. They are generally used on ceilings only, so that the chance of contamination is slight, and the washing and fumigating done routinely should safely disinfect them along with the walls, furnishings, etc. Acoustical engineers are alive to the peculiar needs of hospitals and since these tests, several new and better methods of acoutical treatment have been devised.

6. Area and Pattern Effects in Absorption Measurements, JOHN S. PARKINSON, *Johns-Manville Corporation.*

The coefficient of absorption of an acoustical material as obtained by the reverberation

chamber method varies with the area tested and the shape of the sample. A theoretical explanation of this phenomenon is outlined, showing that the results cannot be attributed entirely to edge affects, and explaining the discrepancies which appeared when the diffraction theory was applied to the tests.

Test results show the efficiency of various patterns and arrangements of treatment. It can be shown that the absorption coefficient is proportional to $K(p/A)$ where p is the perimeter of the individual sample and A the area. It can be shown also that the absorption per square foot of total pattern area is always proportional to the ratio of treated to untreated area, regardless of the pattern arrangement. This relation is formed to hold good for all frequencies with the same material, but not for different materials. Typical questions of construction and design can be answered as a result of the data.

7. Recent Advances in Sound Absorption Measurements, V. L. CHRISLER and W. F. SNYDER, *Bureau of Standards.*

Part I. Measurement of Sound Absorption by Oscillograph Records. The method is much the same as that described in the previous paper except the decay is measured through as much as 50 decibels. The results agree very closely with those obtained by the ear using the usual reverberation method. The coefficients for a few materials are given as determined by both methods.

Part II. Absorption of an audience. The absorption of an audience has been determined when seated in different kinds of chairs. The results of these measurements are given with the suggestion that they should be checked by other observers.

SUPPLEMENTARY PROGRAM

1. Measurement and Calculation of Sound Insulation, VERN O. KNUDSEN, *University of California at Los Angeles.*

The term "reduction factor" has been given different meanings. Architects, builders and even many acoustical engineers, are not aware of these different meanings, and consequently unnecessary confusion arises whenever insulation data from different laboratories are compared. Thus, the "reduction factors" for the same type of panel measured at the Bureau of Standards and at the Riverbank Laboratories may differ as much as fifteen decibels. Buckingham and also Davis have shown that the quantities measured at different laboratories cannot be directly compared. However, these quantities may be converted into quantities—the coefficients of transmission for the panel—which do admit of direct comparison. Under suitable test conditions these coefficients should be independent of the test room and also of the method of testing. The writer has made some insulation measurements by three different methods—typical of the methods now in use at different laboratories—and obtains good agreement for the coefficients of transmission by all three methods. By assigning reasonable properties to the test rooms at the Riverbank Laboratories it is shown that Sabine's results on the insulation of rigid partitions are in essential agreement with Chrisler's results. A simple formula is suggested for calculating the insulation properties of rooms.

2. Approximations in Determining the Total Absorption of a Room, C. A. ANDREE, *University of Wisconsin.*

In the formulae for the decay of sound in a room the total absorption is customarily taken equal to $\Sigma_i a_i s_i$, where a_i is the absorption coefficient for any uniform area S_i. It is shown that this method of determining the total absorption is an approximation requiring the assumption

"that sound which is reflected from material having a given reflection coefficient has a probability of encountering, on its *next* reflection, material with a like coefficient which probability is equal to the ratio of the area of that material to the total area present." This assumption requires in general an amount of "bending" of the lines of propagation in excess of what may normally be expected from dispersion phenomena. The author suggests a method of attack which permits one to account for varying degrees of dispersion and applies this method of attack to the simple case of a cubical room. Numerical values of, $\bar{a}$, the average absorption coefficient are determined which shows the effect of assuming different degrees of dispersion, and the effect of altering the distribution of the absorbing material in the room.

3. Movies of Vocal Cord Speech and Voice Quality Vocal Cord Function, G. OSCAR RUSSELL, *Phonetic Research Laboratories, Ohio State University.*

These are the first moving picture experiments to be obtained, bearing on the fundamental problems involved in a consideration of speech and voice quality vocal cord function.

Most of our theories of speech have heretofore assumed a harmonic complexity of tones produced by the actuator or vocal cords. The moving picture photographs of the heretofore inaccessible interior larynx interior and lower throat now show for the first time that this is an impossible postulate.

Speech and voice quality differences have heretofore been ascribed to a function of the total air volume cavity capacities above the vocal cords—in other words to a cavity ton modificatory influence. These pictures likewise prove that these theories are untenable an that a large part of the voice quality and many vowel quality differences may be traced to d function of the interior larynx.

4. Absorption of Adjoining Volumes in Reverberation Calculations, W. J. SETTE, *Electrical Research Products, Inc.*

Theatres with balconies present a different aspect to reverberation calculations than the single volume type. The space under a balcony may contain more absorption in square feet of equivalent open window space than the area of the face opening into the main volume. Heretofore arbitrary values ranging from .25 to 1 have been assumed for the coefficient to assign this connecting area. To obtain a more accurate idea of the absorption effective in the main volume random distribution of sound energy was assumed and equations were derived expressing the percentage absorbed of the energy incident on the area. The apparent coefficient is a function of the average coefficient behind the area and the ratio of the area to the total surface enclosing the space in question, and is different for different assumptions made as to the manner in which reflections occur. The use of the coefficient in reverberation calculations is discussed.

Note: 281 persons registered at this meeting of the Society.

NEW YORK CITY'S NOISE ABATEMENT COMMISSION

By Shirley W. Wynne
Health Commissioner of New York City

Just why the Department of Health came to pick upon the problem of noise abatement may puzzle you who are accustomed to looking upon it as an engineering problem. As a matter of fact, the Department of Health did not seek out the problem, the problem sought out the Department.

Over a period of years people have been writing us to ask our aid in abating the noises that bother them. Theirs was a practical problem—how to get their proper sleep and how to be efficient on their jobs in the midst of this modern phenomenon of city noise. With instinctive logic they turned to the Department of Health to help them get rid of conditions that materially affected their well-being.

From householders disturbed by factory noise or traffic noise or drilling or riveting, from men and women disturbed by stentorian radio concerts in neighboring apartments, from school principals who found their year's work slowed up by the interference of street noise that penetrated into class rooms, from the dean of a woman's college who complained that the class rooms facing on the street had become practically useless, from business offices, from settlement houses, these letters came. We employed a sort of pinch-hitting diplomacy to bring about peace in most of these instances. But the great fact of city-wide noise persists.

It is doubtful, however, that these people even suspect how much noise affects them in their daily lives. Physicians from the earliest times have known that noise works hardship on invalids and convalescents. In this city of seven million persons there are many who are ill, many more who are not ill but are without great physical resistance—young children, aged men and women, those who are not properly nourished, those who are exposed to particularly hazardous occupations, and it is a physician's first thought that noise might in many cases be the straw that breaks the camel's back, the determining factor of physical—and even of mental—health.

This belief of physicians'—call it intuition if you will—is based on practical experience and is a part of the art of healing rather than a definitely established scientific doctrine. But surely such practical experience extending throughout the ages that physicians have devoted

their every energy to healing the ills of mankind forms a sound beginning for modern research.

I am surprised—and at the same time not surprised—that not until recent years have scientists turned their attention to the effects of noise on human beings. I am surprised, because as I have said, physicians always have known that invalids stand a much better chance of recovery if they have quite surroundings. I am not surprised for the very reason that only within our own times has noise developed into the ubiquitous, unceasing fact that it now is—a constant source of wear and tear on the healthy as well as on the sick.

(I am purposefully not mentioning the fact that noise—loud and continued—can and does cause deafness, because I must keep in mind the average city dweller, not especially those employed in the noisy occupations that have long been known to produce deafness. Ten years ago there were listed twenty-five such noisy trades and today it has been found that taxi-driving and truck driving can be added to that list of twenty-five.)

Only since the beginning of our present mechanical age has the jar and clang of metal on metal become the accompanying symphony of our lives—a diabolical symphony prolonged for the entire twenty-four hours of the day in many parts of our city. And while it has not been found to produce such deafness as workers in noisy trades have suffered from, it has been shown to affect people in a subtle way whether they are conscious of it or not. Experiments have shown that it affects them at their work, although they may go on with their task and get it done somehow. And experiments have shown that noise affects people in their sleep whether or not they are awakened by it.

It is significant that the demands of industrial efficiency first revealed the extent to which noise can interfere with the activities of well people. I believe it was in 1910 that Hugo Münsterberg spoke of the way noise undermined efficiency. One of his most vivid examples was that of the woman working in a print shop where she was exposed to the constant rumble of trucking in a nearby passage; when she was moved from this environment to quieter surroundings her work improved 25 percent. A study of the economics of industrial fatigue made by Florence revealed that noise, more than muscular strain, eye strain, or poor air, was the cause of absences in a large factory.

Then there is the record, cited by Dr. Harold Ernest Burtt, telling what happened to a group of experienced workers in a European fac-

tory under the conditions of noise and of comparative quiet. This group working next to a boiler shop with its accompanying noise was found to produce 60 imperfections in assembling 80 temperature regulators. Removed to a quiet place, this same group was found to assemble 110 regulators in the same time it had formerly taken them to assemble 80—and with only seven imperfections!

Dr. Burtt also relates another instance where it was suspected that poor production in a certain factory was due to the noise of an electric fan. The fan was stopped and production jumped 12 percent in spite of the poorer ventilation. This group of instances showing the effect of noise on industrial efficiency is not large enough to form the basis of scientific conclusions, even yet, but added to the common daily experience of office and factory workers forms an imperative hint that a deeper study should be made.

The beginnings of this deeper study have already been made by such men as Morgan, Laird, Poffenberger, Watson, Cassell, Dallenbach, Talbot, and Darlington—to name a few of the men who are rapidly adding to our knowledge.

In 1926, Professor Morgan made a study of noise, which he described before the 16th Safety Congress held in Chicago. He said, "The research I did assumed what most people think, that noise does something to an individual. I had the subject working at a very definite object which I thought occupied all the interest and attention he could muster. . . . . Then I introduced the most powerful ghastly noise I could . . . . I thought something might be happening to the individual although he was working rapidly (during the noise). I put a spring under the keys he had to operate and found very definitely that he pressed the keys with greater vigor when the noise was on and there was also an increase in muscular energy. I took the breathing record and found a remarkable change."

The results of these studies of Professor Morgan's showed: 1, that noise produces a change in heart action, resulting more in irregularity than in acceleration or retardation of the average rate; 2, that subjects vary in their response; 3, that different sounds have different effects; 4, that even the suggestion "horrible din" to a hypnotized subject quickens the pulse, indicating that the emotional attitude of the subject toward the sounds may be of greater significance than the quality of the sound itself. Professor Morgan was quick to add that although he suspected that the emotions were most stirred by noise it was not

to be assumed that therefore the effects of noise are negligible, but on the contrary they are even more harmful.

This matter of the emotional effects of noise, noted by many other investigators also, has been taken up by Dr. Foster Kennedy in his study made for the New York Noise Abatement Commission, He says, "Long before the emotions are actively disturbed there are disturbances by reason of the stress of vibrations in the heightened pulse rate, heightened blood pressure, some irregularities in heart rhythm and, most important of all, in the increase of pressure on the brain itself. Emotion is only the end product of the process; the undoubted effect of constant noise is disturbance of the blood vessel apparatus, and the increase in the degenerative processes in the heart and arteries."

Dr. Kennedy's conclusions are based on the findings of the many researches made during the last ten years by other investigators and on his own most interesting experiments at Bellevue Hospital to determine the effects of noise on brain pressure. In these latter experiments the subjects were persons who in the past have required operations on the skull with the removal of bone and replacement of scalp—persons otherwise in perfect health. A small drum containing a partial vacuum was placed to the soft area of the head in such a way as to cause no pain or discomfort to the subject. This drum registered all the vibrations in the brain lying against and underneath it by communicating the vibrations to a fine recording needle that impinged on a carbon-blackened paper on a revolving drum.

First, the normal pulsations of the brain and its pressure were recorded on the carbonized paper and then the pulsations under the influence of noise. The noise of exploding inflated paper bags raised the brain pressure to four times normal for seven seconds and this pressure although not remaining at the peak did not return to normal until 30 seconds had passed. Curiously, this increase in brain pressure was greater than that produced by injections of morphine or nitroglycerine—two drugs known to raise the brain pressure more than any other drugs.

Many of you here today were privileged to hear Dr. Donald A. Laird review before the December meeting of this Society the present array of experimental literature dealing with the effects of noise. What different kinds of noise do to the motor functions; to the simple cerebral functions, such as discriminating between colors, experiencing sensations of smelling, discriminating between lifted weights, and memorizing nonsense syllables; to the more complex cerebral functions such as the taking of intelligence tests, the multiplication of three-place by three-

place numbers, a learning test, etc; to the respiratory functions of both animals and humans; to the cardiovascular functions, to the emotional functions; and to the organism at work—these many phases of investigation were reviewed by Dr. Laird at that time. He summarized by saying that "noise, as is commonly understood, has widespread effects upon the living organism. In general, these effects are not desirable."

Coming back from these laboratory experiments to the greater experiment in the tremendous laboratory of New York City, where seven million people are trying to live under such noise conditions as have never before prevailed in the entire history of civilization, I would say that New Yorkers agree with Dr. Laird that the effects of noise are not desirable.

There is another factor to be considered here. Considering the fact that noises go on affecting people at work and at rest, whether or not these people are conscious of them, it is likely that the thousands of letters complaining of city noises do not even begin to give a true picture of the harm noise does to those of us who dwell here.

That, however, is a matter for study,—merely one of the pieces of work definitely before us and an essential part of the work that the Noise Abatement Commission has set out to do. I say it is merely a part, because, after all the problem before us is not only to know what is happening in this sound-ridden city, but to correct the noise abuses as we discover them.

Like all practical problems, the one of noise abatement in New York City is complex—as complex as the city itself. It involves not only the comfort of the citizens, but also their very trades, their customs, their laws, and their amusements.

Looking at the situation, I was appalled at its magnitude and it widespread ramifications. It required for its solution the combined thought of men skilled in many different lines of endeavor—medicine, neurology, otology, law, law administration, building, engineering, acoustics, and automotive design.

In other words, here was this great noise laboratory crying out for workers to use it, carry on their researches, bring about results. Fortunately we have the workers right here, men who accepted the challenge and who have been giving of their time and remarkable talents ever since they were asked to serve on the Noise Abatement Commission last October. Theirs is no mere lending of their names to committees, but a real service to the community involving much hard work.

To facilitate its work, the Noise Abatement Commission divided it-

self into committees, each working independently on its own problems and, where necessary, referring its work to the other committees for further elaboration. The work of the Committee To Study The Effect Of Noise On Human Beings is to give the Commission as a whole definite data on how much noise is allowable. The work of the Committee On Building Code And Construction is two-fold: 1, to study the means of reducing the noise of building construction and rapid transit operation; and 2, to prepare a new building code, based on this study and on the study of such work in other cities. The work of the Committee On Practical Application of Remedies is to evolve methods of enforcing noise abatement measures; the work of this committee is of deeper significance than the mere legal aspects of its investigations—it aims at the development of real community feeling for the suppression of noise. Underlying the work of these committees is the foundation formed by the findings of the Committee On Noise Measurement And Survey, under the direction of Dr. Harvey Fletcher. I am very glad that I have this opportunity of expressing my personal appreciation, as well as that of the Department of Health, for the splendid cooperation and unselfish works of the engineers who have carried on this survey under the direction of Dr. Fletcher. Dr. Galt and Dr. Steinberg with the splendid cooperation of their fellow engineers of the Bell Telephone Laboratories and Mr. Parkinson and other engineers of the Johns-Manville Corp., have measured the city's noise at all hours of the day and night, and under all conditions of weather.

This outline of the work of the Commission illustrates more clearly than could an abstract statement how essential the contributions of specialists in many fields are to the final solution of the noise problem in our city. Obviously the part that acoustical experts have played and will play in this gigantic task is essential to the carrying on of all phases of the work. How can we know the quality and quantity of the noise with which we must deal without their aid? How can we legislate against noise unless we can describe it in unmistakable terms of loudness and annoyance qualities? How can the physiologists and psychologists correlate their findings without a standard for describing the noises used in their experiments?

You have given us much assistance already and you can give us much in the future. As I see it, one of the first aids you can supply us with is a standard method for measuring noise and a universally accepted unit by which noise can be as simply measured as electricity or heat.

PRACTICAL METHODS OF NOISE MEASUREMENT

By E. E. Free
The E. E. Free Laboratories, New York City

1. The "Noisiness" of a Noise

Practical noise measurement, as now demanded for many industrial and other purposes, usually involve three things. First is a frequency analysis, specifying the pitches of the tones more or less musical in character which are present in the noise. Most noises encountered in practical work do not consist chiefly of individual or periodic impulses but contain tones of definite frequencies mixed together in a way which often obscures their individual musical character; like the unmusical "noise" produced when someone falls on a piano keyboard as contrasted with the musical sounds produced when the same keys are struck in proper order and combination. The average noisy machine, for example, really is singing a limited number of musical tones, each due to the individual vibration of some machine part.

The second item is measurement of the amplitude, intensity or energy content (these words here being synonyms) of the whole noise or of its individual frequencies These two measurements of frequency and amplitude are ideally combined in the "acoustic spectrogram", analogous to the optical spectrogram and indicating on a single curve having frequency for its horizontal axis the amplitude of each frequency prominently present in the noise.

Most noise measurements made for practical purposes involve, however, another and less familiar factor; the measurement of loudness or "noisiness" as perceived by the ear. This is necessitated by the fact that the average human ear varies greatly in sensitivity to sounds of different frequencies. Frequencies greater than some 16,000 or 18,000 cycles per second are not heard at all by the majority of adults. Frequencies below about 200 cycles per second are heard much less loudly, at the same amplitude, than are frequencies in the range over which the average ear is most sensitive, which is between 2000 and 3000 cycles per second. These sensitivities of average ears to sounds of different frequencies have been worked out chiefly by Fletcher and his associates and reduced to a curve of hearing now generally accepted as standard.[1]

Since interest in noise usually is dictated by its effects on average

[1] Harvey Fletcher, "Speech and Hearing", D. van Nostrand Company, New York City, 1929, especially page 157.

human beings this relation between frequency and loudness becomes of great importance in practical measurements. Two vacuum cleaners, for example, may be emitting the same total sound energy; one of them at the frequencies to which the ear is most sensitive in the neighborhood of 2500 cycles per second, the other at frequencies notably above or below this range. The first machine will seem much louder than the second because of this difference in pitch.

To be suitable for the majority of present-day practical purposes a noise-measuring method must yield information about the frequencies present, about the amplitudes of each and about the effects of these frequencies on the average ear. The loudness or "noisiness" of a noise may be defined as the integrated effect of the components of the noise on the ear. It usually is neither necessary nor possible to make distinction between "noise" and any other kind of sound. The acoustic expert may be called upon to measure as noise anything from the neighbor's piano playing to the crash of thunder of the bang of a cannon.

2. Noise Units

There is much present disagreement about units, definitions and methods of measuring sound intensities, a situation which at least two committees are now endeavoring to cure. Older measurements were made as a rule in ergs, watts, dynes per square centimeter or other familiar physical units. However, the range of amplitudes in noises is so great that the use of these ordinary physical units involves almost astronomical magnitudes and may obscure the vital point of the effect of noises on the ear. The response of that organ being at least approximately logarithmic, a thousand-fold multiplication in the physical intensity of a sound causes, for example, but a three-fold increase of sensation.

Because of this fact there is coming to be general agreement that noises should be measured in some variety of sensation unit related logarithmically to the scale of physical intensities. The telephone unit of the decibel is of this type and is growing in favor for noise measurement also. This unit is a ratio or measure of amplification; two sounds differing by one bel or 10 decibels, for example, when the louder is ten times the physical intensity of the fainter, by 20 decibels when the physical ratio between them is 100, by 30 decibels when the ratio is 1000, and so on. For noise measurement in decibels it is necessary, therefore, to adopt what might be called a zero noise, at which the measurement scale may begin and which is to serve as the base from

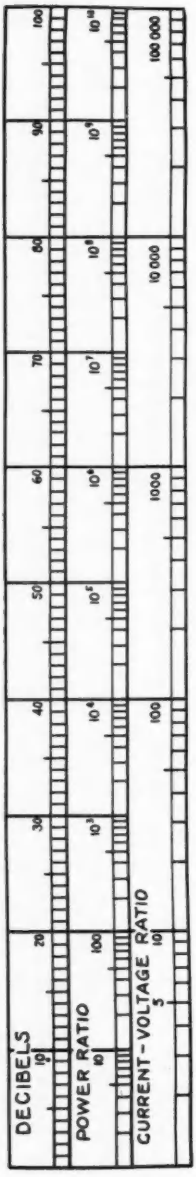

FIG. I. COMPARATIVE CHART OF DECIBEL SCALE.

which the increase in decibels is to be measured. There is increasingly general agreement to adopt as this zero of the noise scale the faintest sound which the ear can hear at the frequency to which that organ is most sensitive. This minimum, in physical units, is approximately 7×10^{-16} watts per square centimeter.[2]

Agreement is less near about units for measuring the noisiness of a noise; that is, its effect on the average ear. For this purpose the ratio, expressed in decibels, to the accepted zero of the scale should be weighted in accordance with the frequency of the sound, thus taking into account the varying sensitivity of the ear. There is as yet no general agreement as to how this weighting should be done.

In our own laboratory and pending pronouncement by some adequate authority, we accept as our noise unit the ratio in decibels of the noise being measured to the minimum noise of that frequency which can be heard by the average ear; that is, the amplification in decibels above the ear's threshold of hearing at that frequency. If more than one frequency is involved the decibels of amplification for all are averaged to give the intergrated figure. As will appear in a later section of this paper, this intergration can be made automatically.

3. HISTORICAL

Older methods of noise measurement were concerned chiefly with a rough frequency analysis; as accomplished, for example, by the familiar resonators of Helmholtz or König, either used with the ear as an indicator of intensity or attached to manometric flames. Among other older apparatus, the Rayleigh disc[3] still has uses as a measurer of

[2] Fletcher, *loc. cit.* pages 153–159.

[3] Lord Rayleigh, "The Theory of Sound", second edition, Macmillan and Co., London, 1896, volume 2, pages 44–45.

physical amplitude but is too fragile for the majority of practical measurements.

Mechanical and optical oscillographs like the phonodeik of Professor Dayton C. Miller,[4] the phonelescope of Dr. H. G. Dorsey[5] or the Low-Hilger audiometer;[6] electro-magnetic oscillographs, one of the best of which is the Westinghouse Osiso;[7] or cathode-ray oscillographs like that developed recently by Professor Frederick Bedell,[8] all have been applied to noise measurement.[9]

Although useful for special purposes, these instruments have been largely replaced for practical work by the electric instruments presently to be described.

For complete frequency analysis of more or less continuous sounds, yielding an acoustic spectrogram suitable for nearly any purpose of noise study, an admirable electric method has been developed by Wegel and Moore of the Bell Telephone Laboratories.[10] For many practical purposes, however, the necessary instrument is both too costly and insufficiently portable. There gradually have been developed, therefore, two simpler electric methods of noise measurement, usually called the audiometer method and the acoustimeter method.

4. Audiometer Methods

A new epoch in practical noise measurement began with the adaptation to this field of the audiometer, an instrument developed by engineers of the Bell Telephone Laboratories primarily for the measurement of hearing and deafness. In 1925 this instrument was applied by Lemon

[4] Dayton C. Miller, "The Science of Musical Sounds", Macmillan and Co., New York, second edition, 1922, pages 78–88; S. Herbert Anderson, "Design and Calibration of a Phonodeik", Journal of the Optical Society of America, vol. 11, pages 31–44, July, 1925.

[5] Dorsey's bulletin, September, 1921; H. G. Dorsey, Gloucester, Mass.

[6] Hilger bulletin, August, 1923; Adam Hilger, 24 Rochester Place, Camden Road, N.W.1, London, England.

[7] J. W. Legg, "Oscillography", Electrical Journal, vol. 24, pages 268–272, 341–346, 398–405, June-August, 1927; also bulletins obtainable from the Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.

[8] Frederick Bedell and Jackson G. Kuhn, "Stabilized Oscilloscope with Amplified Stabilization", Review of Scientific Instruments, vol. 1, pages 227–236, April, 1930.

[9] Further references to earlier methods of measuring noise and other sounds will be found in "Akustische Messmethoden", by Ferdinand Trendelenburg, published as chapter 13, volume 8, Handbuch der Physik, edited by H. Geiger and Karl Scheel, Julius Springer, Berlin, 1927.

[10] R. L. Wegel and C. R. Moore, "An Electrical Frequency Analyzer", Bell System Technical Journal, vol. 3, pages 299–323, April, 1924.

and by Snook[11] to the measurement of automobile noise and by ourselves in making the first noise survey of New York City.[12]

Several types of audiometer exist and may be used for noise measurement, all depending upon the same fundamental principle of comparing the noise to be measured with a standard noise of known character and intensity. In its simplest form, as used originally by Snook, Lemon and

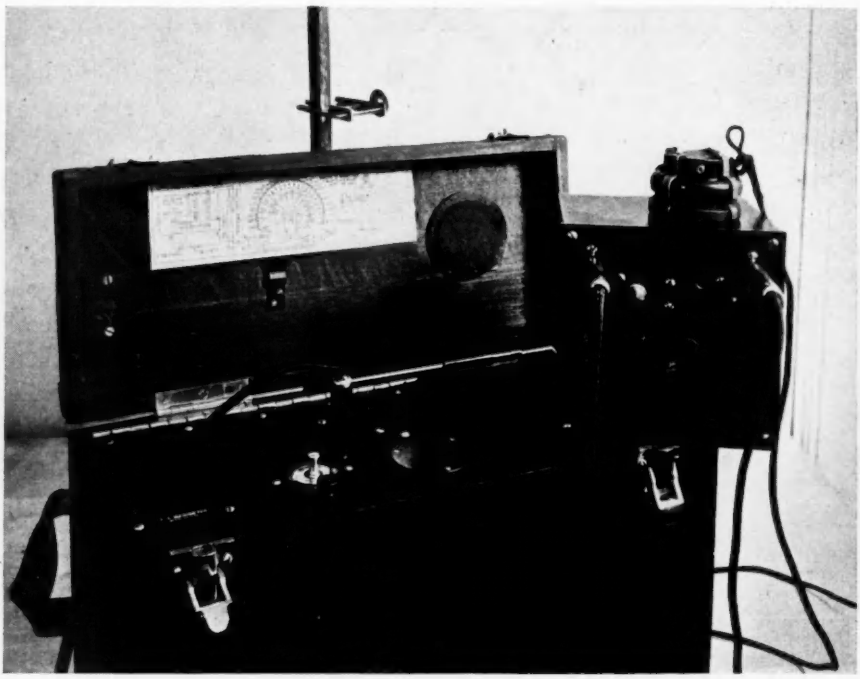

FIG. II. A STANDARD AUDIOMETER.

The number 3-A audiometer, as described in the text. The buzzer and batteries are inside the larger box. The smaller box at the right contains the attenuator, which is calibrated for use in noise measurement by determining the decibels corresponding to the dial figures originally designed to measure deafness. On top of the attenuator is the special telephone receiver with the off-set face plate described in the text.

ourselves, the noise-measuring audiometer consists of a buzzer to produce the standard noise, an attenuator and a telephone receiver.[13]

[11] H. Clyde Snook, "Automobile Noise Measurement", Journal of the Society of Automotive Engineers, vol. 17, pages 115–124, July, 1925.

[12] E. E. Free, "Measurements of the Street Noise in New York City", Physical Review, vol. 27, page 507, April, 1926. E. E. Free, "How Noisy is New York?", the Forum, vol. 75, no. 2, pages xxi–xxiv, February, 1926.

[13] This is the 3-A audiometer of the Bell Telephone Laboratories, equipped with a special telephone receiver, as described.

The electrically-operated buzzer generates a set of electric oscillations designed to contain virtually all frequencies over the usual noise range from about 200 cycles per second to about 3000 cycles per second. This electric oscillation is supplied to the telephone receiver which then emits the corresponding standard noise. The amplitude of this noise may be altered in known steps by the attenuator, which may be any type of non-inductive potentiometer. The telephone receiver is provided with a supplementary face plate fitted to the front of the receiver with an open space between. Thus the standard noise from the receiver enters the ear as usual, through the hole in the face plate. Noise from the surroundings enters the ear simultaneously through the gap between that plate and the front of the receiver itself.

The operator listens to both noises simultaneously using the attenuator to vary the loudness of the noise from the telephone receiver until this noise is just "masked" or rendered inaudible by the noise entering from the surroundings. The louder this extraneous noise, the louder must be the noise from the telephone and the higher the corresponding setting of the attenuator in order that the standard noise shall be just below the point at which it can be heard in spite of the noise from the surroundings. The scale of the attenuator having been calibrated once for all, for example by testing the instrument against noises of known loudness, the scale settings of this instrument at which masking is just complete provide a measure of the noise then entering the ear.

It has been found in practice that this method gives reasonably accurate and reproducible measurements of noises which are more or less continuous and which do not differ too greatly in frequency from the noise produced by the buzzer. If there is a substantial difference in frequency the readings are less reliable; for example, if the noise being measured is a high-frequency whine while that from the buzzer is of intermediate or low frequency. This is for the reason that the masking effect in the ear provides a true comparison of amplitudes only if the sounds being compared are substantially similar in character. If the frequency pattern of the noise to be measured and that of the audiometer buzzer are widely different, as they necessarily are in many practical problems, the possible accuracy of the instrument is decreased greatly.

To correct in part for this error audiometers are sometimes used in which the noise to be measured is matched against three buzzer sounds instead of one; one containing relatively high-pitch tones, a second chiefly of medium-pitch tones and the third of low-pitch tones. The

average of the three comparisons thus obtained is taken as the actual loudness of the noise. In recent applications of this method phonograph records and vacuum-tube amplifiers have been used to produce the standard sounds which are then attenuated and used for comparison, as before. Thus it is possible to make comparisons of the noise being measured with single tones from standard-frequency records or with "warble tones" also from special phonograph records and designed to vary rapidly in frequency over any desired range.[14]

In another variant of the audiometer method, instead of matching the known and unknown noises in the ear by allowing one to mask the other, the noise to be measured is picked up by a microphone, amplified by a vacuum-tube amplifier and fed into a telephone receiver alternately with the standard noise from the audiometer. A throw-over switch permits the operator to listen first to one noise, then to the other, a match between the two being attained by judgment of the ear that they are alike. This method seems, in practice, to be neither much more accurate than the matching method or much less so. The method of masking is simpler since it requires no microphone or amplifier for the noise to be measured. Comparison of the external noise and the audiometer noise by placing the telephone receiver alternately against and away from the ear has been suggested but has proved, in our hands at least, to be less reliable than the method of masking.

One characteristic of the audiometer methods is that the results are given directly in loudness or noisiness units, since the ear is used as an indicator of comparison and the attenuator is calibrated in these units instead of units of physical energy. In comparing audiometer measurements reported in the literature with others reported in terms of physical energy it is important to bear this difference in mind.

5. Acoustimeter Methods

New methods of noise measurement which have come into use rapidly during the past four years and which promise soon to replace all others depend upon the conversion of the sound energy into electric energy. There is small agreement about names; some of the instruments are called "noise meters", others "phonometers", still others "acoustimeters". The principle is much the same in all. The noise energy is picked up from the air or elsewhere by some form of microphone or

[14] See, for example, Rogers H. Galt, "Methods and Apparatus for Measuring the Noise Audiogram", THIS JOURNAL, vol. 1, pages 147–157, October, 1929.

other pick-up. The electric oscillations thus produced are amplified by a suitable vacuum-tube amplifier. Finally, the output of this amplifier is measured by a suitable meter.[15]

The chief requirements of such a system are that its amplification and other operating characteristics should remain constant from time to time and that it should maintain a constant ratio of conversion of sound energy into final electric energy over the frequency range concerned. In radio language, the amplification characteristic of the system should be flat over its frequency range. This range should extend, in our

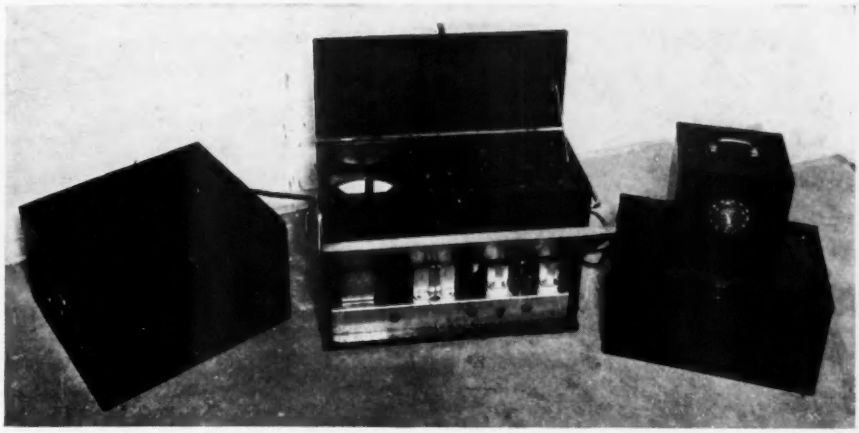

FIG. III. A MODERN ACOUSTIMETER.

The instrument recently developed by the C. F. Burgess Laboratories, Inc., and ourselves. The acoustimeter proper is in the center, containing the amplifier (below), the meter (above at the left) and the attenuator (above at the right). On the left is the battery box for the amplifier. Above at the right are the condenser microphone and its amplifier, in a wooden box. Underneath this is the battery box for the microphone. All connections between the boxes are made by convenient plugs and jacks.

opinion, from not more than 60 cycles per second to not less than 9000 cycles per second. To obtain a system which does have these characteristics is chiefly a matter of good design in microphone, transformers and other parts and of design of circuits and operating voltages to avoid feed-back and other inaccuracies to which vacuum-tube ampli-

[15] See, for example, Floyd A. Firestone, "Technique of Sound Measurements", Journal of the Society of Automotive Engineers, vol. 19, pages 461–466, November, 1926; T. Spooner and J. P. Foltz, "Study of Noises in Electrical Apparatus", Journal of the American Institute of Electrical Engineers, vol. 48, pages 199–202, March, 1929; R. F. Norris, "The Acoustimeter", Projection Engineering, vol. 1, page 43, September, 1929; E. C. Wente and E. H. Bedell, "A chronographic method of measuring reverberation time", THIS JOURNAL, vol. 1, pages 422–427, April, 1930.

fiers are unfortunately prone. A suitable acoustimeter is much more than an ordinary amplifier with a meter attached.

One instrument of this type, recently developed jointly by the C. F. Burgess Laboratories of Madison, Wisconsin, and ourselves, has the necessary flat amplification characteristic over a frequency range between 60 cycles per second and approximately 10,000 cycles per second, is satisfactorily stable in operation and is capable of measuring with ac-

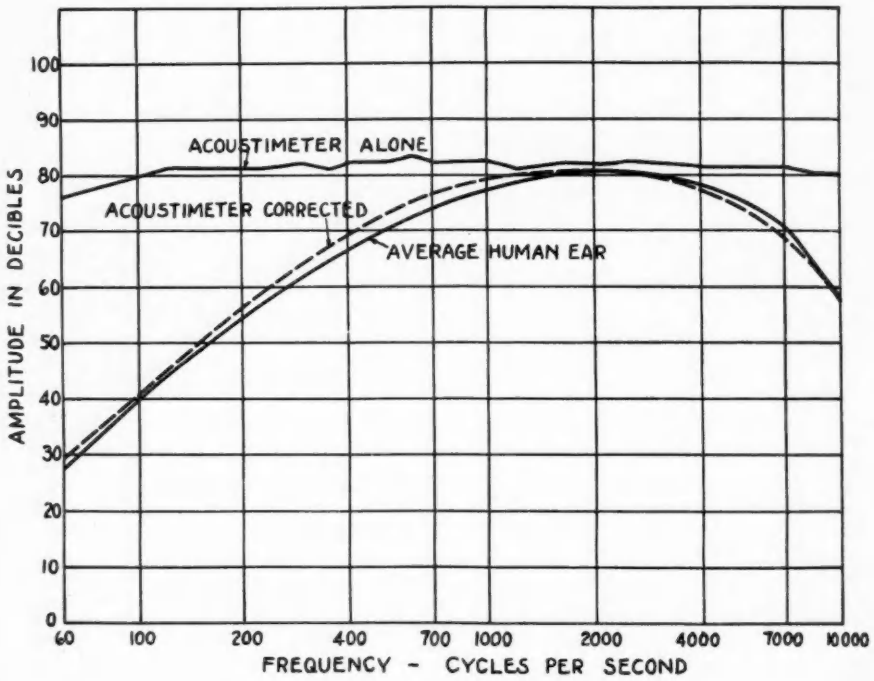

FIG. IV. CHARACTERISTICS OF THE ACOUSTIMETER.

The upper curve shows the response of the acoustimeter alone, measuring sounds of uniform intensity at the different frequencies. The lower solid curve shows the response of the average human ear at different frequencies, being Fletcher's well-known curve of hearing inverted. The broken line shows the response of the acoustimeter working with the electric network which corrects its readings to indicate loudness or "noisiness".

curacy any sound within the frequency range mentioned and within an amplitude range between approximately the threshold of hearing and more than 120 decibels above that threshold, equivalent to a magnification of more than one thousand billion times.

In its simple form an instrument of this type indicates noise intensities in the equivalent of physical units; that is, without any indication of of frequency of weighting of the readings for differences in subjective

loudness. It is possible, however, to attach to the simple instrument a suitable electric network of condensers and inductances the transmission characteristics of which for different frequencies approximate the sensitivity of the human ear at the same frequencies. With this network in the circuit the readings of the instrument are given automatically in decibels weighted to indicate intensities above the threshold of hearing for each frequency; that is in the noise units or noisiness units above described.

As now in service in our laboratory this instrument is provided with a simple throw-over switch. With the switch in one position the correcting network is out of the circuit and the instrument reads the intensity of a noise in decibels based on physical units. With the switch in the opposite position the network is thrown into the circuit and the instrument reads weighted decibels or noise units. Either or both measurements may be made, as desired.

In the present state of knowledge of electric networks for special responses at different frequencies, like that just described, it probably is impossible to produce a network which will correspond exactly to any one definite curve drawn to represent the sensitivity of the human ear. However, a fair degree of approximation can be attained; probably enough to bring the response of the instrument well within the limits of variation between individual normal ears.

For some purposes, for example in locating the sources of noise in a machine, it may be desirable not only to have the integrated noise measurement weighted to correspond with the frequencies present so that it will indicate the relative effect on the ear, but also to obtain a more or less complete acoustic spectrogram, indicating the relative amplitudes of the chief individual frequencies which are present. With the acoustimeter above described an approximation of this can be accomplished by attaching other electric networks to constitute a series of band-pass filters adapted to pass into the instrument one after another selected frequency bands; 60 to 200 cycles, for example; then 200 to 500 cycles, and so on. The energy in each such band of frequencies thus may be measured separately or recording meters may be attached to write automatically an approximation of the complete acoustic spectrogram. The chief present limitation of this method is that separations between the frequency bands thus selected by a system of electric band-pass filters is less sharp than might be desired but this presumably will be improved as we advance in knowledge of such filter design.

If a part of the complete range of frequencies from 60 cycles per second to 10,000 cycles per second and a part of the amplitude range of 120 decibels can be sacrificed, an acoustimeter of this type can be constructed in cheap and easily portable form for noise measurement anywhere, for noise inspection of machines or other manufactured articles, for test of larger machines for noisiness after installation, for measurements in the field of architectural acoustics and for the majority of other purposes for which noise measurements ordinarily are made.

6. Noise Measurement With Tuning Forks

Following recent successful measurements of street and other noises made in England by Davis[16] using an extremely simple method with a tuning fork it was suggested to me by Dr. Harvey Fletcher that this method might be worth consideration for general purposes. Accordingly comparative tests were made of street noises in New York City, simultaneous measurements being made with turning forks, with the 3-A audiometer used in our survey of New York City noise six years ago and with an acoustimeter as described above. In all instances the very simple tuning-fork method gave results closely comparable with the other two methods, discrepancies being no greater than the normal variation of street noise from moment to moment.

The fork is struck in some standard manner which can be kept reasonably the same from time to time. In our tests it was struck with reasonably equal force against the steel frame of the door of a taxicab. It is then held as close as possible to the ear with the flat side of a prong toward the head. With a stop-watch the observer notes the time which elapses before the continually decreasing note of the fork becomes inaudible. Since the external noise tends to mask this tone of the fork precisely as it does with the standard tone of the audiometer, the amplitude of the fork at the instant it becomes inaudible serves as a measure of the external noise. In our tests readings were made in triplicate and averaged.

As pointed out by Davis, the decay of the sound of the fork follows an approximately logarithmic law just as does the response of the ear to sounds. Accordingly, by measurements made with known sound intensities or in absolute quiet, it is possible to calibrate any given fork so that the time in seconds read from the stop-watch in Davis' method indicates the loudness in decibels of the noise against which the fork was

[16] A. H. Davis, "Measurements of Noise by Means of a Tuning Fork", Nature, vol. 125, pages 48-49, January 11, 1930.

heard. Three or more forks of different frequencies may be used and readings made with each, thus partially correcting for imperfect masking at a single frequency just as is done in using a three-tone audiometer.

Davis' method seems unquestionably worth further test for noise survey work where only moderate accuracy is required and where an acoustimeter is not available. The chief precaution necessary seems to be that the fork be calibrated in the same way in which it is to be used and preferably by the same person. Contrary to what might be expected, no extraordinary precautions seem to be necessary in striking the fork or holding it in uniform position in front of the ear.

7. Comparison of Methods.

The acoustimeter furnishes the most flexible, accurate and reliable method of noise measurement so far available. These are the only portable instruments which yield reliable information, even approximately, about the chief frequencies present. Readings may be obtained either in purely physical units or in noisiness units, corrected for the sensitivity of the ear. The instruments have the disadvantage of being relatively expensive and not easily portable although both of these handicaps are being overcome rapidly, especially for instruments not requiring extreme range or precision.

Audiometer methods have the advantage that the instruments are simple, relatively cheap and easily portable. Their disadvantages are that discordance in frequency may affect the results seriously and that little information is obtainable about the frequencies present.

The tuning-fork method is promising for approximate surveys, especially of street noise, and is extremely cheap and simple. Its disadvantages are that the necessity of repeated readings makes it relatively slow, that it lacks an objective record and that it resembles the audiometer methods in yielding little information about frequencies.

June 18, 1930.

RESULTS OF NOISE SURVEYS
PART I. NOISE OUT-OF-DOORS

By Rogers H. Galt

Bell Telephone Laboratories

I. Introduction

The purpose of a noise survey of a locality is to study the space and time distribution of noise intensity, the frequency composition of the noise, the contributions of various noise sources, the relation between the annoyance effect of the noise and its physical and auditory characteristics, and the effectiveness of methods of noise reduction. The extent to which each of these phases of the noise problem has been investigated heretofore has depended upon the point of view of the investigator and upon the apparatus employed. From one standpoint or another, any audible sound may fall within the category of noise; hence the variety of possible noise surveys is almost unlimited. Not many such surveys have been carried out, however, partly because the appropriate apparatus is of recent development; nor has any extensive comparison been published between the results obtained in different places and with different instruments. It has therefore seemed worth while to assemble such previously published results as are available, and certain new observations, in the present series of papers, of which this paper deals with noise out-of-doors.[1]

II. Methods of Noise Measurement

A general description of the methods and instruments used in measuring noise having been presented before the present symposium by Dr. E. E. Free,[2] only a brief mention of the subject need here be included.

In measurements of the audiometric type, the human ear is employed together with some device which permits the assignment of a numerical magnitude to the noise effects. In certain surveys the buzzer audiometer[3] has been used. The tone from an electric buzzer (of fundamental

[1] The other papers in the series "Results of Noise Surveys", presented before the Acoustical Society of America, May 9, 1930, are:

Part II—"Noise in Buildings"—R. S. Tucker

Part III—"Vehicle Noise"—J. S. Parkinson.

Part IV—"Noise Reduction"—J. S. Parkinson.

[2] "Summary of Previous and Existing Methods of Noise Measurement", E. E. Free; paper presented before the Acoustical Society of America, May 9, 1930.

[3] H. Fletcher, "Speech and Hearing", p. 103.

frequency 160 cycles per second) connected to a telephone receiver is adjusted in intensity until it is judged to be as loud as the noise, or until it is masked by the noise. In the latter case, the noise is admitted to the ear through openings between the ear and the receiver diaphragm, the receiver cap being of the type called off-set; in these and in all measurements by the method of masking or threshold observation, the quantity measured is the deafening produced by the noise.

In some more recent surveys, audiometric observations of the masking type have been made with an apparatus[4] supplying a series of warbling tones, each tone located in a different part of the frequency spectrum. The deafening effect of a noise is thus measured in each region of the sound spectrum, and the measurements, when plotted against frequency, result in a curve which is termed the audiogram of the noise.

Another device for making audiometric measurements of a noise is that described by Dr. A. H. Davis.[5] He employed a watch and a tuning fork; always striking the fork in the same way, he measured

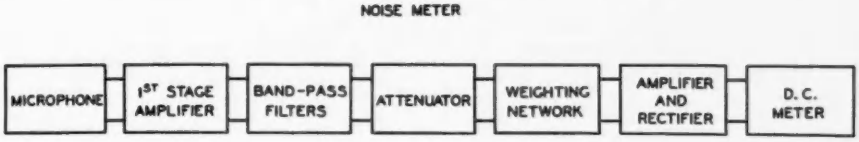

FIG. 1.

the time required for the tone to decay to a level equal to that of the noise, as judged by the ear, or else to such a level that the tone was masked by the noise.

A different type of observation, employed in recent surveys, is independent of the observer's ear and yields a purely physical measurement. The apparatus consists of a pick-up device, or microphone; an amplifier, with or without a frequency weighting network; a distortionless attenuator; and a rectifying device with a meter. In some cases, a series of band-pass filters is arranged for insertion between two stages of the amplifier. The instrument may be calibrated for a particular type of noise by noting the meter reading when the noise is at the threshold of audibility; any greater reading of the meter gives the level of the noise above the threshold,—that is, the sensation level. A simplified diagram of this apparatus, which is termed a noise meter or an acoustimeter, is shown in Fig. 1.

[4] Jour. Acous. Soc. Am., Vol. 1, Oct. 1929, p. 147.
[5] Nature, Vol. 125, No. 3141, p. 48.

The frequency weighting network employed in some noise meters is so adjusted that the overall characteristic of the system for single frequencies is as shown in Fig. 2. This characteristic is based upon that of the normal ear,[6] the significance of which may thus be expressed: if a certain meter reading results when a pure tone of 1000 cycles at a sensation level of 30 units agitates the microphone, then the same meter reading will be obtained for any other pure tone of equal loudness. Starting with any single frequency tone at the intensity just defined,

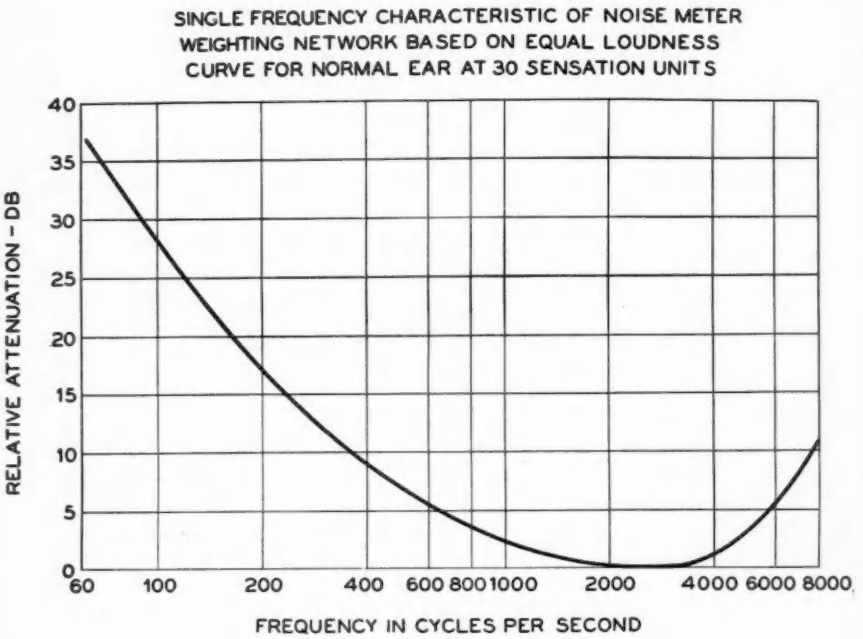

FIG. 2.

if the level of the tone is altered by a chosen amount, say 10 decibels, the reading of the noise meter changes 10 decibels. It is well known, however, that a change of 10 decibels in intensity produces unequal changes in loudness at different frequencies; hence the noise meter cannot be said to measure the loudness of a pure tone at other levels than that for which the weighting network was adjusted. The meter does, however, if calibrated accordingly, measure approximately the sensation level of a pure tone in the frequency region from 1000 to 5000 cycles, where the curve of Fig. 2 is substantially flat.

[6] H. Fletcher "Speech and Hearing", p. 230.

The interpretation of the meter reading for a complex applied wave is more involved than for a pure tone. The rectifier is not a linear device; one type of rectifier, a thermocouple, integrates the squares of the component amplitudes; another type of rectifier, a vacuum tube device which can be used instead of, or in parallel with, the thermocouple, may be even more complicated in its action. In neither case does the noise meter sum up the components of a complex wave in the same manner as does the ear in producing loudness. Hence, if two successive complex waves differ greatly in composition, the corresponding meter readings will not compare the waves as they are compared by the ear. There is thus a definitely arbitrary element involved in the use of the noise meter employed in any particular survey; another noise meter, having a single frequency characteristic different from that of Fig. 2, and employing a different integrating device, would in general yield different measurements. The arbitrary feature is inevitable, however, as no known apparatus has been constructed capable of imitating the ear in the integration of the components of a complex wave.

Much of the difficulty involved in these considerations is removed by the realization that the complex waves encountered in out-of-door noise surveys are usually of the same general composition. This was proved in a survey of New York City; partly by the frequency analysis afforded by a set of four band-pass filters included in the equipment, which could be inserted after the first amplifying stage following the microphone; partly by the analysis afforded by the phonographic audiometer. Since these analyses showed that the total energy of the out-of-door noise waves is usually distributed throughout the spectrum in much the same manner, the different noise meter readings may be regarded as actually comparable, to within a reasonable degree of accuracy; that is, if the noise meter gives for one ordinary street noise a certain reading, and for a second common noise a reading 10 decibels greater, no large error can be involved in the conclusion that the sensation level of the second noise is 10 decibels greater than that of the first.

A noise meter[7] employing a network approximately following the single frequency curve of Fig. 2 was used in the Noise Abatement Commission Survey of New York; this instrument was calibrated in terms of a street noise, phonographically reproduced in the laboratory.

[7] This instrument was designed by Mr. T. G. Castner of the Bell Telephone Laboratories, and was constructed under his direction.

The reproducer was electromagnetic in type, generating a currnt which traversed an attenuator and an amplifier, and finally agitated a loud speaker system situated in a sound-proof room. By means of the attenuator, the intensity of the reproduced noise was adjusted to the threshold value by each of seven observers having normal hearing. The attenuator setting corresponding to threshold level being thus determined, the attenuator was then adjusted to cause 55 decibels less attenuation, so that the level of the street noise reproduced in the sound-proof room was 55 decibels above threshold. The observer's head was so placed that the ear was held close beside the microphone throughout each test, the ear and the microphone being thus situated in almost the same way with respect to the source of noise and the surrounding objects. The noise wave picked up by the microphone in this manner was regarded as equal in level to the wave affecting the ear, namely as 55 decibels above threshold. The resulting scale reading R of the noise meter was observed, and the difference, $\Delta = 55 - R$, was taken as the increment which must be added to the noise meter scale reading to obtain the sensation level of the noise.

This calibration experiment was performed with a reproduced room noise, as well as with the street noise already mentioned, and also with three warbling tones located respectively in the frequency ranges 160–240 cycles, 750–1500 cycles, and 3100–5400 cycles. The value of the increment Δ was practically the same for the street noise, the room noise, and the 750–1500 cycle warble, but was several decibels smaller for the low pitched warble and several decibels greater for the high pitched warble. Such a result would be expected in view of the use of a weighting network based on the curve of Fig. 2. In fact, if the noise meter were to be used to determine the sensation level exactly, a different value of the increment would be required for each different type of noise. Since it is not feasible to determine the proper increment for each noise, a single value of the increment is adopted for all noises with the understanding that for a noise differing radically from the calibrating noise, the adopted increment may be in error by as much as ten decibels. In general, the error will be considerably less than this, probably not greater than ± 3 decibels. That is, the error involved in determining with the noise meter the sensation level of an ordinary sustained street noise is usually not greater than ± 3 decibels. In view of this inaccuracy, however, it is considered more correct to use the term noise level rather than sensation level for the value obtained with the noise meter, remembering that the noise level is nearly, but

often not exactly, equal to the sensation level of the noise.

Since the noise meter does not in general measure either the sensation level or the loudness of a noise, the choice of the proper frequency weighting network is a matter of some uncertainty. A network following the curve of ear sensitivity at threshold causes more attenuation of the very low and very high frequencies, relatively to that of the middle frequencies, than does a network following the curve of equal loudness at a level of 30 decibels; this difference is in the same direction, but greater, if comparison is made with the curve of equal loudness at a level of 60 or 70 decibels. In view of this, it would seem that in the measurement of noise levels of about 30 decibels above threshold, the use of the curve of ear sensitivity at threshold would attenuate the extreme frequencies too heavily, whereas the curve of equal loudness at the 30 decibel level would allow these frequencies to affect the noise meter somewhat more nearly as they affect the ear at this level. On this basis the 30 decibel loudness curve was used in the survey of noise in buildings, described in Mr. Tucker's paper, where the noise level is not far from 30 decibels. For a survey of noise in streets, where the average level is perhaps 60 to 70 decibels, the same argument would indicate that the weighting network should follow the curve of equal loudness at the level 60 or 70 decibels. This choice was not made, however, in the Noise Abatement Commission Survey of New York, for it was considered that because the loudness curves at 30 and at 60 or 70 decibels do not differ greatly in slope, the advantage of adopting the 60 or 70 decibel curve would be small, whereas by using the 30 decibel curve, the observations would be directly comparable with those obtained in the survey of noise in buildings.

While considering the interpretation of the noise meter readings, attention should be called particularly to one other feature of this instrument, the time constant. When a noise begins suddenly, rising at once to a certain intensity and then remaining steady, the indicating needle of the noise meter does not instantly move to a steady position, but rises gradually, requiring two seconds to reach approximately a steady position, for one instrument which has been used, and about five seconds for other instruments. When the noise ceases, the needle takes a similar time to settle back to zero. Consequently, if a noise fluctuates rapidly and repeatedly, as outdoor noises often do, the noise meter needle will not follow the noise level exactly, but will round off the peaks and valleys. The range of instantaneous noise levels actually occurring will thus often be greater than the range of noise meter read-

ings. This discrepancy is greatest when an isolated noise maximum or minimum occurs of very short duration, such as the noise due to an explosion, and becomes negligible when the maximum or minimum is sustained over a period of two to five seconds,—for example, the sound of a passing elevated train.

The unit of measurement is the decibel, whether the quantity measured is the sensation level of the noise, or the amount of deafening produced by the noise. The difference in level, in decibels, of two sounds is by definition equal to ten times the common logarithm of the ratio of the two intensities,—that is, the power ratio. When the sensation level of a noise is expressed as a certain number of decibels, the noise intensity is that many decibels greater than the threshold intensity of a noise of the same type, observed in a quiet place. When the deafening due to a noise is expressed as a certain number of decibels the meaning is that the intensity of the test tone which is just audible in the presence of the noise is greater, by the given number of decibels, than the intensity which is just audible in a quiet place.

The deafening produced by a particular sound may be different in amount and in frequency distribution from the deafening produced by another sound of equal sensation level. It is therefore not possible, in general, to derive the deafening from the sensation level, or vice versa. Measurements have shown, however, that for most of the ordinary complex sounds which constitute out-of-door noise in a city, there is a fairly constant difference between the level of the noise, measured with the particular type of noise meter already described, and the deafening produced by the noise in the frequency region from 750 to 1500 cycles per second. It is found that if the noise level has been measured, the deafening in this region may be obtained by subtracting 14.5 decibels; if the deafening has been measured, the sensation level may be found by adding 14.5 decibels. The results of such computations will usually be correct to within ± 5 decibels, provided the predominant pitch of the noise is in the range 750 to 1500 cycles per second.

Using this reduction increment of 14.5 decibels, it is possible to bring into comparison many results obtained by the two different methods, physical and audiometric. In order to extend the comparison to include the deafening measurements made with the buzzer audiometer, the difference has been determined between the noise level indicated by the noise meter and the deafening simultaneously measured with this

audiometer. It has been found that the noise level is about 17 decibels greater than the buzzer deafening.

III. Noise Due to Specific Sources

In measuring the noise produced by a common out-of-door source such as a steamboat whistle, a motor truck or an elevated street railway train, it is usually not practicable to isolate the particular source from all other noise sources or otherwise to control the general conditions

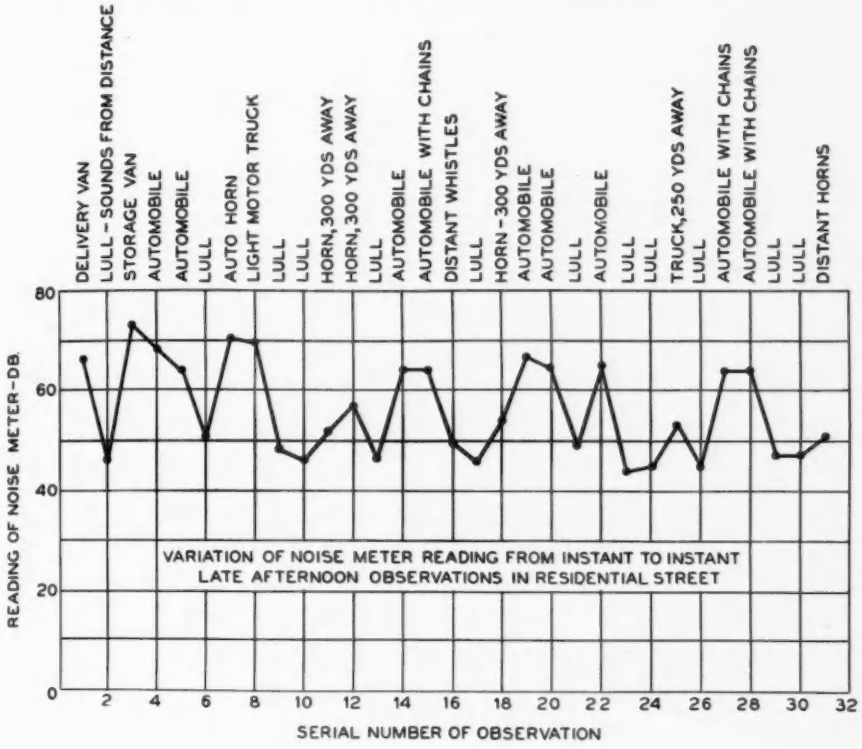

Fig. 3.

of the test. Ordinarily, the observer conveys the measuring instruments to a place where the desired observations may probably be obtained, and then awaits a chance opportunity for measurements free from significant interference by other noises. To an observer on the street, the aggregate noise at any instant is usually caused by several, or many, sources rather than by a single source; but as time passes, there will be short periods when the observer's hearing informs him that one or another single source definitely predominates over all other sources. If the margin of predominance is sufficiently great, the noise meter

reading will be determined practically by the single source alone. A series of such observations is illustrated in Fig. 3, which shows suc-

NOISE LEVELS OUT OF DOORS DUE TO VARIOUS NOISE SOURCES

SURVEY OF NEW YORK CITY NOISE ABATEMENT COMMISSION		NOISE LEVEL	OTHER SURVEYS	
DISTANCE FROM SOURCE	SOURCE OR DESCRIPTION OF NOISE		SOURCE OR DESCRIPTION OF NOISE	SURVEY NO.
FEET		DB		
		130	THRESHOLD OF PAINFUL SOUND	4
		120		
2	HAMMER BLOWS ON STEEL PLATE-SOUND ALMOST PAINFUL (INDOOR TEST)		AIRPLANE; MOTOR 1600 R.P.M.; 18 FT. FROM PROPELLER	5
		110	AERO ENGINE UNSILENCED – 10 FT	4
		100		
35	RIVETER			
15-20	ELEVATED ELECTRIC TRAIN ON OPEN STRUCTURE	90	PNEUMATIC DRILL – 10 FT.	4
			NOISIEST SPOT AT NIAGARA FALLS	2
15-75	VERY HEAVY STREET TRAFFIC WITH ELEVATED LINE	80	HEAVY TRAFFIC WITH ELEVATED LINE, CHICAGO	7
15-50	AVERAGE MOTOR TRUCK		VERY NOISY STREET N.Y. OR CHICAGO	1
15-75	BUSY STREET TRAFFIC	70	VERY BUSY TRAFFIC, LONDON	4
15-50	AVERAGE AUTOMOBILE			
3	ORDINARY CONVERSATION			
15-300	RATHER QUIET RESIDENTIAL STREET, AFTERNOON	60	AVERAGE SHOPPING ST., CHICAGO	6
			BUSY TRAFFIC, LONDON	4
15-50	QUIET AUTOMOBILE			
	MINIMUM NOISE LEVELS ON STREET:	50	QUIET AUTOMOBILE, LONDON	4
			QUIET ST. BEHIND REGENT ST, LONDON	4
15-500	IN ENTIRE CITY DAY TIME – MIN. AVERAGE			
50-500	IN ENTIRE CITY DAY TIME – MIN. INSTANTANEOUS	40		
50-500	IN MID-CITY NIGHT – MIN. INSTANTANEOUS			
		30	QUIET ST., EVENING, NO TRAFFIC SUBURBAN LONDON	4
		20	QUIET GARDEN, LONDON	4
			AVERAGE WHISPER – 4 FT.	3
		10	QUIET WHISPER – 5 FT.	4
			RUSTLE OF LEAVES IN GENTLE BREEZE	3
		0	THRESHOLD OF HEARING	

FIG. 4.

cessive readings of the noise meter observed on a residential street in New York City during the Survey of the Noise Abatement Commission.[7] Observations were made at the rate of about three per minute, each

[7] Hereafter this survey will be referred to as the N.A.C. survey. The results of this survey were presented to the Noise Abatement Commission in May and June 1930, by Dr. H. Fletcher, Chairman of the Committee on Noise Measurement.

reading being taken at a momentarily steady position of the needle on the scale, such as the maximum position when a vehicle passed the microphone. Comparing the readings of 44 to 49 decibels for the lulls with a reading of about 66 decibels for a passing automobile, it is evident that the noise due to the automobile was virtually the sole cause of the meter reading of 66 decibels.

When this procedure is followed in a survey to obtain the noise due to each ordinary source, a number of measurements made upon one type of source, such as the automobile, may be scattered over a fairly wide range of levels. This is of course to be expected, in view of the differences in the construction of different automobiles, in the noisiness of a motor under different conditions of acceleration, in the effect of distance and surroundings, and in similar factors. However, the average of a considerable number of such measurements upon a particular type of source together with the maximum and minimum values, should give a reasonably accurate idea of the general noise level which may be expected from a source of this type. The average noise level for automobiles, and likewise for motor trucks, has been determined in this way from the N.A.C. survey observations and entered with other measurements on the chart in Fig. 4 to contribute to the singificance of the scale of levels there shown. The average values, together with the maxima and minima, are given later in Table 2, for a number of specific sources.

The general form of the chart in Fig. 4 is due to Mr. W. Waterfall.[8] In this chart the data are divided into two parts, observations made in the recent survey of the Noise Abatement Commission of New York being placed to the left of the central scale, and the results of other surveys to the right. This subdivision is made because of the comparatively large amount of material available from the N.A.C. survey, and because the observations of this survey, obtained with the same apparatus, should have a high degree of consistency.

At the extreme right of the chart is a column of "Survey Numbers" which, by aid of Table 1 identify the source of each observation in the column headed "Other Surveys". The order of arrangement of these surveys in the auxiliary table is arbitrary; the experimental method used, and the authority, are given. An attempt has been made to include in Fig. 4 at least one observation from each of the available surveys and to select such observations as are either peculiarly interesting or else readily comparable with observations from other surveys.

[8] W. Waterfall, "Engineering News Record", Jan. 10, 1929.

TABLE 1

EXPLANATION OF SURVEY REFERENCE NUMBERS OF FIG. 4.

Survey Reference Number	Instrument	Method	Reference
1	Buzzer Audiometer	Balance	E. E. Free, "The Forum", Feb. 1926; March, 1928.
2	" "	Deafening	K. P. Royce, special tests.
3	" "	Balance	W. Waterfall, "Eng. News Rec." Jan. 10, 1929.
4	Tuning Fork 640 cycles	Balance or Deafening	A. H. Davis, "Nature", Jan. 10, 1930.
5	Warbling Audiometer	Deafening	W. A. MacNair, special tests.
6	Buzzer Audiometer	Balance	D. A. Laird, "Sci. Amer.", Dec., 1928.
7	Acoustimeter	Physical	R. F. Norris, Results presented before Chicago Board of Health.

At the extreme left of the chart is a column of distances, in feet, from the source of noise to the microphone used in the N.A.C. survey. In general, these distances are expressed as a range, rather than as a single figure; thus for the average automobile, causing a noise level of 65.5 decibels, the distance is given as 15 to 50 feet. The significance of these figures for distance is that, for the great majority of the measurements involved, the automobile causing the noise was within these assigned limits, although in a small percentage of cases the distance was less than 15 feet, or greater than 50 feet. In the N.A.C. measurement of noise at very quiet places, the range of distances is shown as 15 to 500 feet, or 50 to 500 feet, on the basis of the auditory observation of the observers that an appreciable contribution to the noise level was made by sources at those distances.

For a noise as variable as that due to street traffic, the general magnitude may be indicated on a chart of the type of Fig. 4 by an average value about which the noise varies. Thus the average of all the observations plotted in Fig. 3 is about 57 decibels, which is shown on Fig. 4 as the level for a rather quiet residential street. In a similar

way, the average noise level was found and entered on the chart for a typical location having busy street traffic; likewise for a place where the noise was caused by very heavy traffic and an elevated street railway. For each of these locations, and for a large number of others throughout New York, the average was determined of the meter readings taken at about the rate of three a minute for from ten to fifteen minutes. The least of these averages, for daytime tests, is shown on the chart as the minimum average level, at 47 decibels. Of course, this minimum average level is greater than the minimum single reading of the noise meter which is indicated on the chart separately for day and for night tests as the minimum instantaneous level.

In the case of one particular entry in the column of N.A.C. observations in Fig. 4, a reservation should be made. This entry gives the noise level of ordinary conversation out-of-doors, at the distance of 3 feet from the source, as 65 decibels. The only experimental data available, involving accurately known distances, upon which to base this conclusion consisted of measurements made upon two male speakers under rather unfavorable conditions; the general noise level was from 50 to 60 decibels, and a moderately strong wind was blowing toward the speaker, who faced the microphone 3 feet away. The tendency on the part of at least one speaker seemed to be to raise his voice above normal; the resulting figure of 65 decibels may well be somewhat high.

A satisfactory agreement is shown in Fig. 4 between comparable measurements from different surveys. For example, from two of the surveys the conclusion may be drawn that the threshold of feeling for the complex sounds measured is about 110 to 115 decibels above the threshold of hearing and the threshold of painful sounds is 10 or 20 decibels higher; two surveys place the noise level due to an airplane 10 to 20 feet away as 110 to 115 decibels; two surveys place the riveter and the pneumatic drill, two similar sources of noise, in the range 90 to 97 decibels; five surveys (in agreement with a sixth independent observation omitted from the chart for lack of space) give the range of noise levels for busy or very busy street traffic in New York, Chicago or London as from 60 to about 80 decibels,—with the indication that traffic termed "busy" in London is less noisy than that termed "busy" in the American cities;— two surveys agree upon 50 decibels as the noise level produced in the street by a relatively quiet automobile. In view of these and similar checks between the various surveys, the genview of these and similar checks between the various surveys, the general accuracy of the chart of Figure 4 may be accepted as established.

A more detailed account of the noise levels due to numerous common specific sources is afforded by Table 2, from the N.A.C. survey. In this table the minimum, average and maximum observed noise levels are indicated for each source as explained on p. 14 above, together with the distance from source to microphone and the number of observations. For certain sources, such as a police whistle, two entries are made, showing in one case the noise level corresponding to a special observation at a definite distance, in the other case the level ordinarily experienced by a person in the street within a rather broad range of distances. This range of distances was the range which ordinarily obtains when a person on the street chances to hear the given noise as predominant. For some purposes of comparison, it might be desirable to know the noise level due to each source at a single distance. A table of such levels may be deduced approximately from the values given in Table 2 on the basis of the law of propagation of an acoustic wave in open air, namely that the intensity,—the power across unit area,—varies inversely as the square of the distance from the source. In decibels, this law states that if the second distance is twice the first, the noise level at the second position will be six decibels less than at the first. Although this law would not be expected to hold exactly for conditions departing from the unobstructed propagation of sound energy in all directions from a point source, the error is not great under ordinary street conditions provided no obstruction intrudes directly between the observer and the source, and provided the distance of the observer from the source is sufficiently great compared with the dimensions of the source. Even in the case of so extended a source or group of sources as an elevated railway train, the inverse square law of propagation of energy was found to hold approximately for a range of distances of 15 to 750 feet measured at right angles to the rails.

The numerical values in Table 2 apply to the aggregate noise level. In a later section of this paper the results of frequency analysis for certain noises will be given.

The noises which have been measured are principally those due to man and his machines, with a few observations of natural sounds for comparison. Although the latter may be intense[9] and annoying,—for example, a thunderclap,—they are of minor concern to civilized man

[9] The great intensity of the sound produced by an explosive volcanic eruption may be inferred from the distances at which such sounds have been heard. It is said that the sound of the explosion of Mont Pelée, Martinique, on May 8, 1902, was heard at St. Kitts and St. Thomas, 210 miles and 350 miles distant. (see Nature, May 3, 1930, p. 692); and the noise

NOISE DUE TO SPECIFIC SOURCES

SOURCE OR DESCRIPTION OF NOISE	NOISE LEVEL			DISTANCE: SOURCE TO MICROPHONE	NUMBER OF OBSERVATIONS
	MINIMUM DB.	AVERAGE DB.	MAXIMUM DB.		
HAMMERING ON STEEL PLATE, 4 BLOWS PER SECOND		113		2 FT	1
RIVETER: AS HEARD NEARBY	94	97	101	35	16 *
AS HEARD ORDINARILY ON STREET		79.5		200	3 *
BLAST OF EXPLOSIVES OPEN CUT DIGGING		98		50	1
SUBWAY STATION UNDERGROUND: NOISE ON PLATFORM: LOCAL STATION: EXPRESS TRAIN PASSING	88	94	97	15-25	5
LOCAL STATION: LOCAL TRAIN	85	88.5	91	6-30	3
5 TURNSTILES: RUSH HOUR	78	83	91	3-7	19
STEAMSHIP WHISTLE (TESTS NEARBY	92	93	94	115	4
WHISTLE RATHER LOUD (TESTS IN 10th FLOOR OFFICE: WINDOWS OPEN	59	61	65	1450	4
(AS HEARD ORDINARILY ON STREET	47	56	68	2500	14
AUTOMOBILE HORN: 34 TYPES, DIRECTED TOWARD MICROPHONE	72	91	102	23	34
AS HEARD ORDINARILY ON STREET	57	71.5	85	23-100	80 *
ELEVATED ELECTRIC TRAIN, ON OPEN STRUCTURE: AS HEARD NEARBY	85	89	91	15-20	7
AS HEARD ORDINARILY ON STREET	70	81.5	91	15-75	54 *
AS HEARD AT 750 FT	51	57.5	63	750	27
CONSTRUCTION AND EXCAVATION: PILE DRIVER, STEAM OPERATED	84.5	87	90	20-80	18
TWO STEAM SHOVELS, WITH ROCK DRILL	81	82.5	86	50	10
HAMMERING, BUILDING		76.5		100	3
IN BRONX ZOO HOUSE: LION ROARING	87	87	87	15	3
SIBERIAN TIGER ROARING	70	79.5	87	7	15
BENGAL TIGER SNARLING	67	75.5	80	15	11
FIRE APPARATUS (SIREN AND BELL		83		100	1
FIRE APPARATUS (BELL: FIRE CHIEF'S CAR		81		50	1
POLICE WHISTLE AS HEARD NEARBY	80	82	83	15	4
AS HEARD ORDINARILY ON STREET	64	74	83	15-75	53 *
AS HEARD AT 185 FT	55.5	57.5	62	185	6
RADIO LOUD SPEAKER ON STREET	73	79	81	30	10
MOTOR TRUCK: EXHAUST NOT MUFFLED	70	77.5	87	15-50	15
CHANGING GEARS	68	74	83	15-50	7
AS HEARD ORDINARILY ON STREET (NOT INCLUDING HORN)	55.5	73.5	87	15-50	203 *
SUBWAY NOISE ON STREET THROUGH GRATING: AS HEARD 5½ FT ABOVE GRATING	74	77	79	5½	6
AS HEARD ORDINARILY ON STREET	60	69	79	5½-30	17 *
ELECTRIC STREET CAR: MOVING FAST	73.5	76.5	77.5	10-15	10
OVER TRACK CROSSING	68	74.5	83	40-50	28
AS HEARD ORDINARILY ON STREET	63	72.5	83	15-50	129 *
MOVING SLOWLY	68.5	69.5	70.5	10-15	6
SNOW SCRAPING AND SHOVELLING		75		15	1
HORSE-DRAWN VEHICLE: AS HEARD ORDINARILY ON STREET	63	74.5	83	15-50	23 *
ON ASPHALT STREET	47	61	72	15-50	100
MOTOR BUS CHANGING GEARS	68	71	75	15-50	10
AUTOMOBILE: SQUEAKING BRAKES	62	71	76	15-50	10
CHANGING GEARS	60	70.5	83	15-50	10
EXHAUST	64	70	74	15-50	4
AS HEARD ORDINARILY ON STREET (NOT INCLUDING HORN)	50	65.5	83	15-50	162 *
THUNDER	60	64	70	1-3 MI.	9
DOG BARKING, ON STREET	49	63	76	20 FT	12
THREE AIRPLANES, IN FLIGHT OVER CITY		62		3000	2
HORSE TROTTING ON ASPHALT STREET	52	61	65	15	8
SAWING WOOD		61		30	1
CHURCH BELLS	52	57.5	61	1200	5

TABLE 2.

in comparison with man-made sounds, which not only are nearly omnipresent, but are within human control. It is almost entirely the sounds from machines and human activity which make up the totality of noise of the modern city.

IV. NOISE IN A LARGE CITY

1. *Surveys of Cities*

The first extensive noise survey of a large city was carried out in New York by Dr. E. E. Free, and described in "The Forum" for February, 1926, and March, 1928. Other surveys have been made in Chicago, Washington, D.C., and London, England, and in 1929–1930 a second survey of the city of New York was made under the auspices of the Noise Abatement Commission of the Department of Health of the city. Insofar as the results of these surveys are available, they are in general agreement as to the magnitude of the noises due to the principal sources in a large city, and as to the noise distribution in space and time. The noise due to various sources has already been discussed; the distribution of noise will next be considered, and since the only extensive data available are those of the N.A.C. survey, these observations will be used unless otherwise specified.

2. *Extreme Noise Levels*

In the streets of suburban districts, where houses are separated and the general activity of persons and traffic is light, it is probable that the noise level rarely falls more than 5 or 10 decibels below the level of 30 decibels measured in suburban London by Dr. A. H. Davis. In city districts where houses adjoin and the population is dense and active, the minimum instantaneous noise level for streets and parks is probably about 30 to 35 decibels at night, and 35 to 40 decibels in the day. The lowest outdoor instantaneous level measured in a 24 hour test in mid-town New York, on 48th Street near 8th Avenue, was 38 decibels, at 4:40 A.M.; from 6 A.M. to 6 P.M. at this location the minimum was 48 decibels. On Wall Street, in the heart of the financial district, the minimum instantaneous level in a 24 hour test was 48 decibels, at 11 P.M., 2 A.M., and 6:30 A.M. Of all the N.A.C. survey daytime measurements in New York, the two lowest instantaneous levels were 42 and 43 decibels, respectively, in a very quiet residential street and on a university campus.

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due to the eruption of Krakatoa on August 27, 1883, was heard at Alice Springs, Central Australia, and on Rodriguez Island, 2250 miles and 2965 miles distant, respectively,—(see "Earthquakes and Volcanoes", by J. W. Gregory, pp. 29, 30).

A level of 35 to 50 decibels would be produced in an open space by one or two moving automobiles or trucks or street cars, within a radius of a few hundred yards of the observer, or by a person speaking in a normal voice at a distance of 25 to 75 feet; it is improbable than any outdoor place in a large city will at any time be free from such disturbances as these. We may therefore regard the range from 30 to 40 decibels as the lowest outdoor noise level to be expected in a large city.

The maximum outdoor noises measured in the streets of New York are of the order of 90 to 100 decibels; 90 to about 95 decibels correspond-

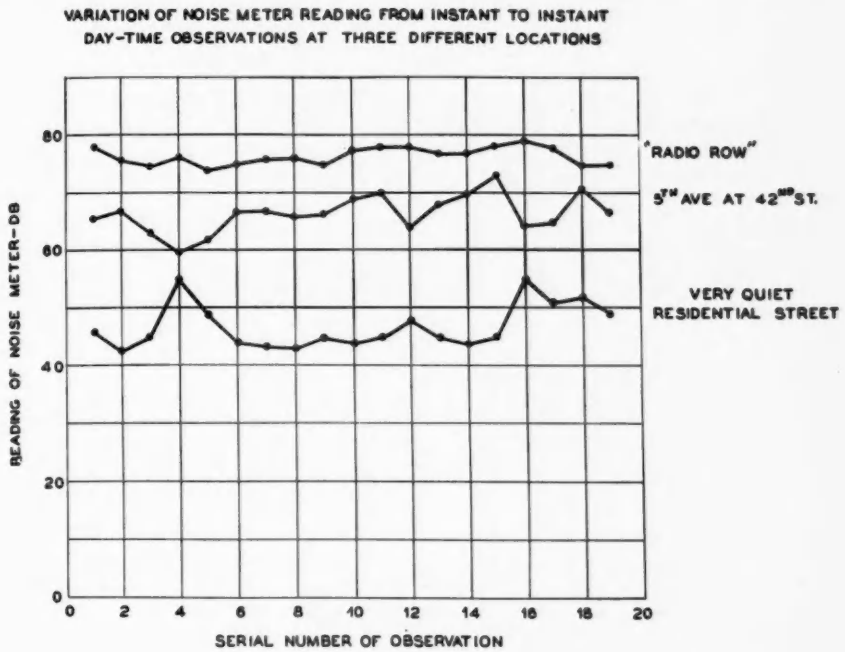


FIG. 5.

ing to observations of elevated trains and steamship whistles; 95 to about 100 decibels having been observed for nearby riveters and for a blast of explosives used in open-cut subway excavation. For very busy streets without construction work or elevated railway, the maximum level observed was 87 decibels. We may thus take 90 to 95 decibels as the normal noise maximum, with an occasional level of 100 or even 105 decibels.

3. *Variation of Instantaneous Noise Level with Time.*

Since the time constants of the noise meters employed in the surveys

are such that from two to five seconds are required for the meter needle to reach an approximately steady deflection after a steady sound has been suddenly produced following a period of silence, the meter readings do not show truly instantaneous noise levels. The crests and troughs are rounded off, and the extreme range of sound observed is less than the actual range. With this in mind, we may examine the actual fluctuations of the noise meter readings observed in the N.A.C. survey of New York.

Making measurements three or four times a minute over a period of about ten minutes, the levels observed usually vary over a range of 10 to 25 decibels. The successive readings of the noise meter experienced on a rather quiet residential street have already been shown in Fig. 3. Fig. 5 gives the readings of the meter for each of three locations differing widely in noise conditions. These plots are sufficient to present a fair picture of instantaneous noise fluctuations at a place on the streets of a large city.

4. *Average Noise Level: Repetitions*

At a location where noise conditions are reasonably similar from day to day a fairly reliable determination of the average noise level is afforded by the arithmetic mean of the noise meter readings taken for an interval of ten or fifteen minutes,—covering three to five traffic cycles,—at the rate of about three observations per minute. This is evident from Table 3, which compares, for each of several locations in New York City, the average noise level obtained on two or more different days.

TABLE 3

Location	Average Noise Level in Decibels on Different Days			
Herald Square	73.2	73.4		
Fifth Ave. and 42nd Street	67.1	67.3	68.0	
Bowery and Canal Street	74.2	74.0	73.6	
Broadway and Canal Street	74.5	69.4	68.7	74.2
Broadway and Houston Street	72.7	70.6		

5. *Variation of Average Noise Level with Time*

The average noise level, taken over a period of fifteen to twenty minutes, has been obtained at intervals throughout a continuous period of 24 hours at each of three New York locations. At one station, the corner

of Canal St. and Broadway, where two of the principal highways of the city intersect, vehicular traffic is heavy throughout the 24 hours. At the second station, on Wall St. near William St., in the financial district, vehicular traffic is not very heavy by day and is quite light at night; the sounds heard here at night are produced principally by miscellaneous sources such as construction work, the underground subway, traffic several blocks away, persons walking and talking, and church bells.

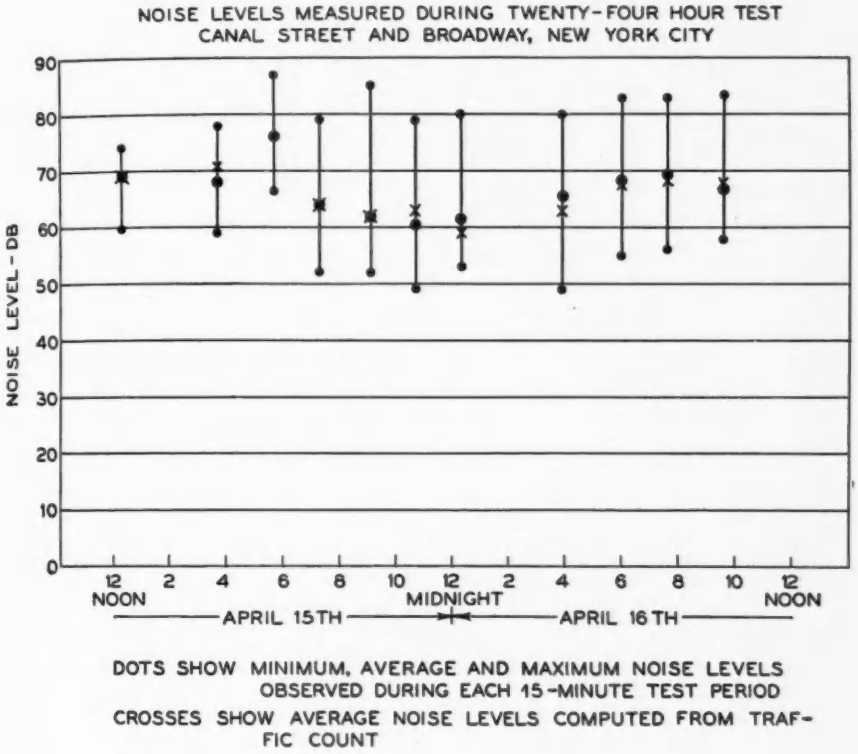


FIG. 6.

The third station, on 48th Street, 185 feet west of 8th Avenue, was in a residential section near the theatrical district and the rather heavy traffic of 8th Avenue. Plots of the observed noise levels are shown in Figs. 6, 7 and 8. It is interesting to note that the 24 hour extreme range of the average noise level at each place covers only about 10 to 15 decibels, which is less than the range of instantaneous levels usually experienced in a period of fifteen to twenty minutes.

6. *Variation of Noise Level from Place to Place*

In the N.A.C. survey of New York, daytime noise measurements were made at about 100 outdoor locations in widely different parts of the city, and the average level was determined for each place. These average noise levels ranged from a minimum of 47 decibels, on the campus of New York University, to a maximum of 80 decibels, at a place on the Grand Concourse where open-cut subway digging was in progress. Eighteen locations have been selected as illustrative of a wide

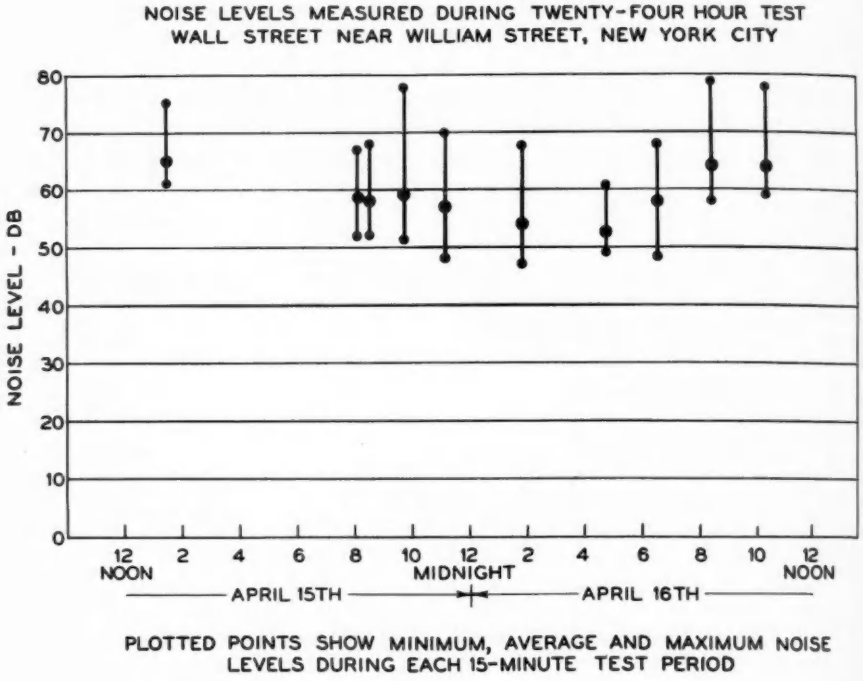


FIG. 7.

range of noise conditions; for each of these locations, Fig. 9 shows the average noise level, together with the minimum and the maximum levels observed.

7. *Noise Due to Street Traffic*

During the N.A.C. survey of New York, a detailed count of street traffic was made at most of the locations while noise measurements were in progress. The results have been summarized in Figs. 10–12, for those places where traffic noise predominated. In Fig. 10, the

average of the observed noise levels in decibels is shown as ordinate, and the total number of vehicles per minute as abscissa, for each station for which the traffic consisted almost entirely of passenger automobiles. Since each ordinate, expressed in decibels, is proportional to the logarithm of the total sound intensity, a logarithmic scale of abscissae has been employed. For a wide range of traffic volumes, the plotted

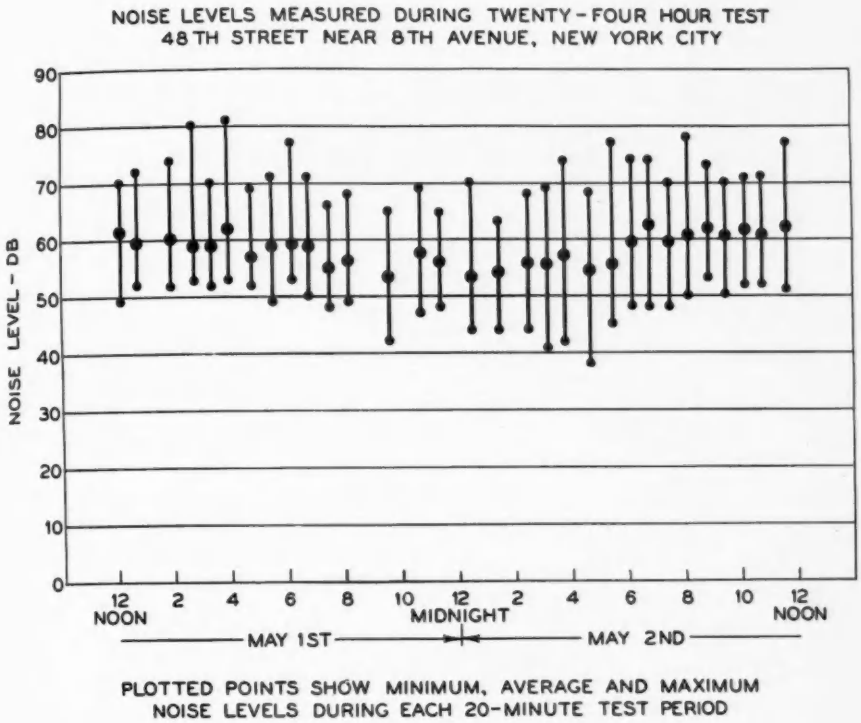


FIG. 8.

points fall close to the straight line indicated in the Figure, the slope of the line being given by the equation

$$Y_2 - Y_1 = 10 \log_{10} X_2/X_1$$

Evidently, if the number of vehicles per minute,—that is, the number of sources of acoustic power,—is multiplied by 10, the average noise level is increased by 10 decibels. Or, if the number of vehicles per minute is doubled, the average noise level is raised 3 decibels.

In Fig. 11, the same results are given, except that the scale of abscissae is linear, and each ordinate is now proportional to the average of

the instantaneous sound intensities at the particular location. For homogeneous traffic the plot shows that the sound intensity is approximately directly proportional to the number of vehicles passing per minute.

The plots of Figs. 10 and 11 establish this relation for traffic composed almost entirely of passenger automobiles; a similar relation may reasonably be assumed to hold for homogeneous traffic of any other composition.

This conclusion regarding the noise at a place where traffic is homo-

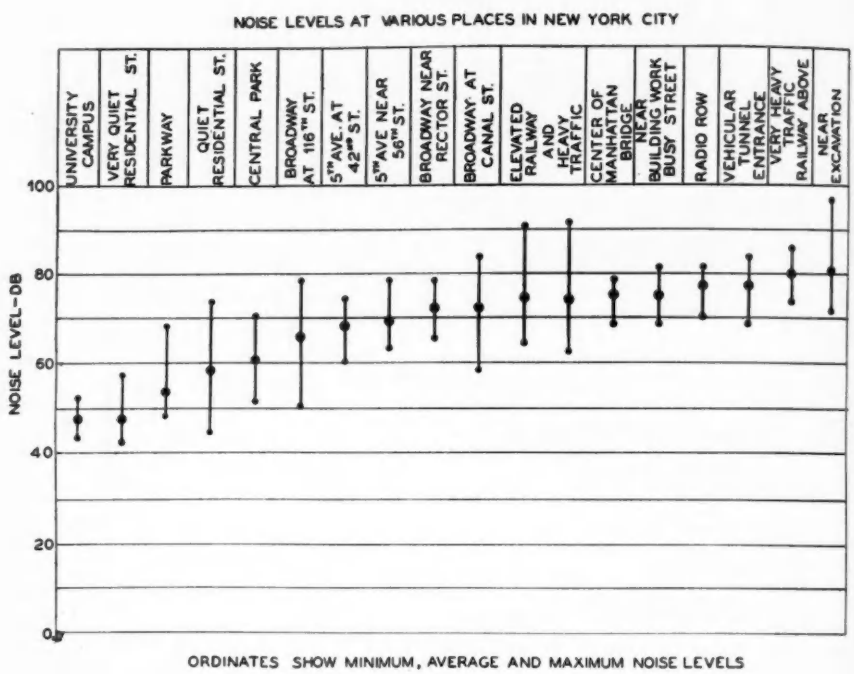


FIG. 9.

genous does not apply to a location where loud noise is present not due to traffic, or to any except very quiet locations when the traffic is less than 5 to 10 vehicles per minute. An upper limit is apparently reached when the the number of vehicles per minute exceeds about 50; for greater volumes of traffic, the noise intensity increases less rapidly than the number of vehicles, due probably in part of the greater width of street involved,—that is, to the greater average distance of the sources form the microphone.

A second result of the traffic observations is shown in Fig. 12. The

average noise level, in decibels, is plotted against the percentage of commercial vehicles as abscissae. In the category of commercial vehicles are included motor trucks, horse vehicles, electric street cars, and motor buses, but not taxicabs. No stations are included having elevated street railways, or having predominant noise due to sources other than traffic. For each station, the average of the observed noise levels has been transformed by computation to the level which would result from traffic of the same composition if the number of vehicles per minute were thirty; in this computation, the law of Figs. 10 and 11 has been assumed. The reference traffic volume of 30 vehicles per minute was chosen as not

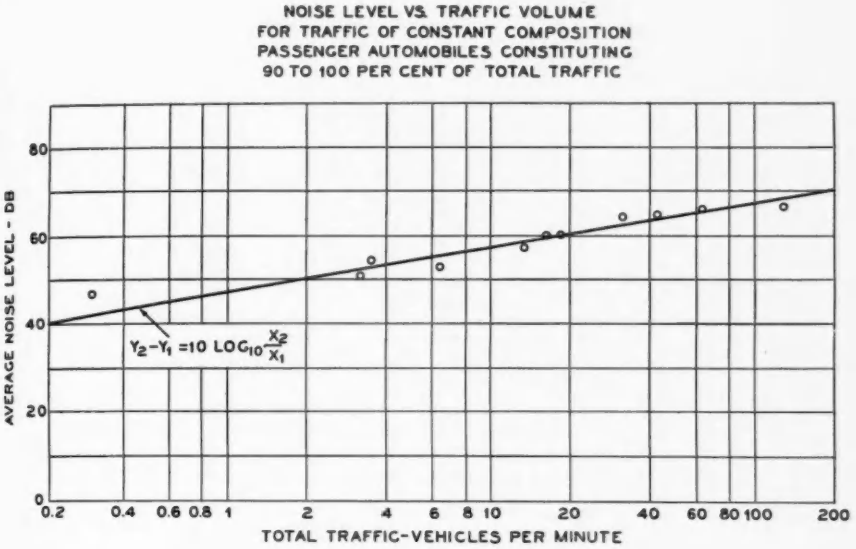


FIG. 10.

far from the average for the stations used. If the straight line drawn on the plot is accepted as a reasonably close representation of the plotted points, the conclusion is that an increase in the percentage of commercial vehicles of 20 per cent results in an increase of about 3.5 decibels in the average noise level.

For a location where traffic noise predominates, it is possible to determine the average noise level to within ± 2 decibels, in general, by aid of Figs. 10 and 12 and a detailed traffic count. The procedure is as follows.

The observed percentages of commercial vehicles, applied as abscissa, in Fig. 12, determines an ordinate,—an average noise level,—by aid

of the line through the plotted points; this noise level refers to a total traffic count of 30 vehicles per minute, and must be reduced to the

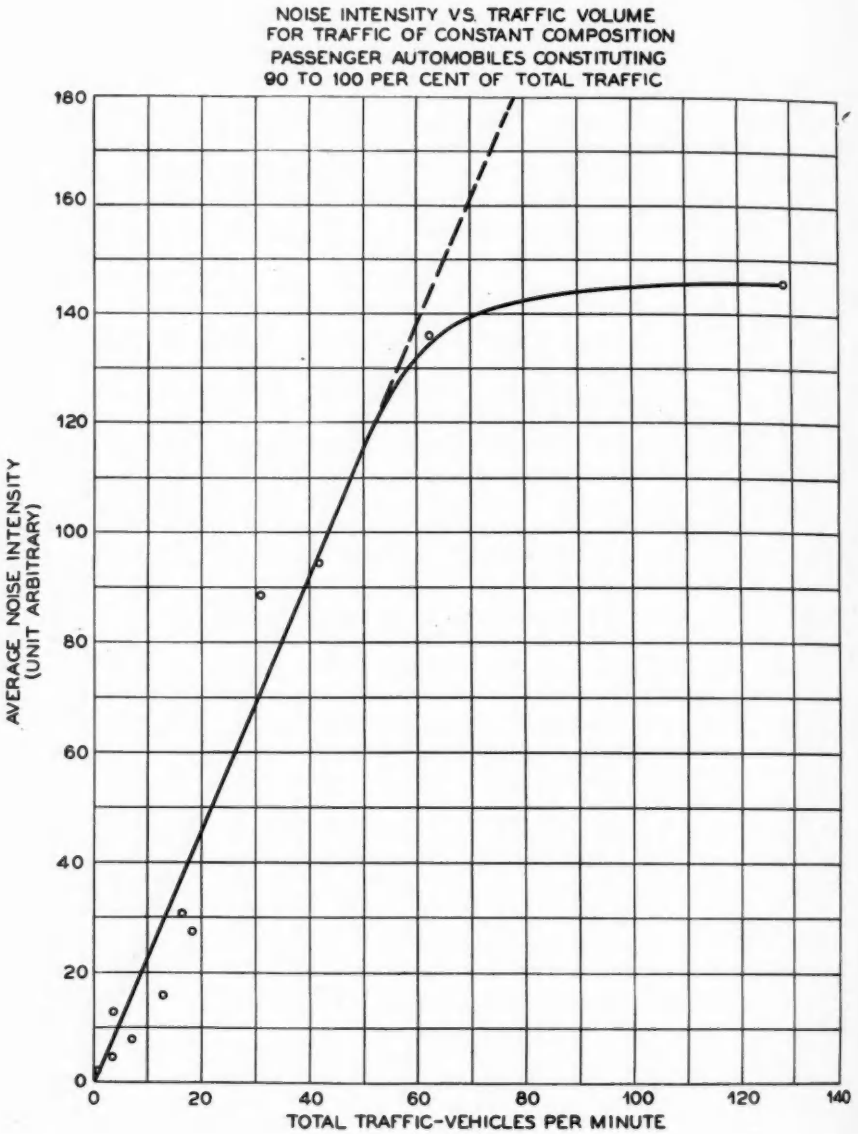


FIG. 11.

observed traffic volume. The reduction increment is the number of decibels corresponding to the power ratio equal to 30 divided by the

observed total traffic per minute.[10] For example, suppose the traffic count shows a total of 15 vehicles per minute, of which 32 per cent are commercial. From Fig. 12, a traffic composition 32 per cent commercial with a total of 30 vehicles per minute results in an average noise level of 68 decibels. The actual number of vehicles has been taken as 15 per minute; the ratio 30:15 equals 2, to which the corresponding increment is 3 decibels. Since the observed traffic count is less than 30,

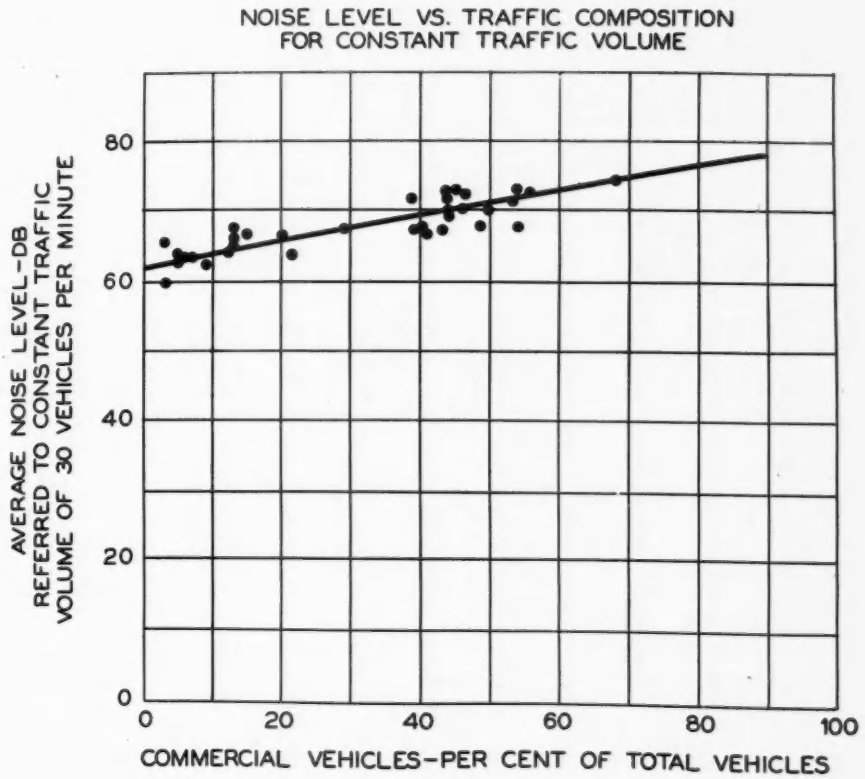


FIG. 12.

this increment is negative in sign. The computed average noise level is therefore $68-3=65$ decibels.

As an illustration, the method of computing the average noise level from the traffic count has been applied to the observations at the corner of Canal Street and Broadway, New York, made during the 24-hour test previously mentioned. A traffic count was available for each of the

[10] The difference in decibels corresponding to a given power ratio can be obtained from the straight line of Fig. 10.

periods of observation except one. In addition to the observed levels, Fig. 6 shows the computed average levels, indicated by the symbol *X*. The mean difference between the observed and the computed average levels is less than 2 decibels.

8. *Effect of Street Traction Upon Noise*

By the term street traction is meant elevated street railways and surface street cars of the common types operated electrically by power supplied over underground cables or overhead trolleys.

In order to get some idea of the noise reduction which might follow the removal of an elevated railway from a street the average noise level was computed, for several Manhattan stations near elevated lines, for two conditions; first, using all observations; secondly, using all observations except those made when elevated trains were passing. It appears that if no trains run, the average noise level is reduced 3 decibels, and the maximum noise level 7 decibels. These figures are applicable to a street with rather busy traffic. For a street which is very quiet except for the noise due to an elevated line, the reduction due to removal of the line would probably be appreciably greater. Of course, no account is taken here of the possible effect of removing the elevated structure.

At a number of locations near surface street car lines, the effect of removing the street car line was estimated by the process used for elevated lines, comparing the results of all observations with the results when observations were omitted involving the noise due to passing street cars. The average noise level is reduced by about 1 decibel, and the maximum usually by 0 to 3 decibels, when the street car observations are omitted. These figures, like those for the elevated railway, apply to rather busy streets, and would be greater for streets which are generally quiet except for street car lines.

It was found that street cars moving rapidly, say at 15 miles per hour over a certain stretch of track, produced an average noise level of 76.5 decibels at a point 10 feet distant, whereas at speeds of about 6 miles per hour over the same track the noise 10 feet away was 69.5 decibels. The noise produced by a street car at a rail crossing is about 6 decibels greater on the average than the noise on unbroken track.

V. RESULTS OF FREQUENCY ANALYSIS

1. *Frequency Analysis of Noise*

A physical analysis of noise into four frequency bands was accomplished in the recent survey of New York by means of band-pass

filters, the bands being: Below 500 cycles; 500 to 1500 cycles; 1500 to 3000 cycles; and above 3000 cycles. The apparatus in tandem with the filters was not distortionless, a frequency weighing network being permanently included of which the single frequency characteristic followed approximately the curve of Fig. 2. Consequently, when the meter readings corresponding to the various filters are compared, it must be remembered that the comparison is not between the total amounts of power conveyed by components in the different bands, for the network discriminates against the very low and the very high frequencies.

Typical results of the filter analysis are given in Figs. 13 and 14.

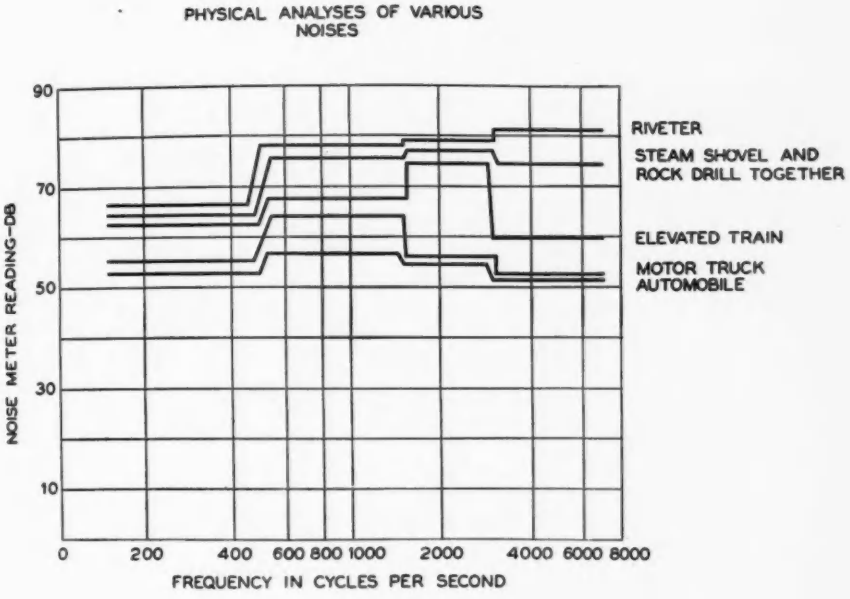


FIG. 13.

Although the shape of the plots of Fig. 13 is by no means uniform, indicating considerable differences between the waves due to various specific sources, the result of summing up a large number of sources is shown by Fig. 14 to be an aggregate street noise which, however it may vary in level, usually retains substantially the same relative distribution of intensity.

2. *Frequency Analysis of Deafening*

In the frequency analysis of the deafening due to noise, the spectrum was divided into three bands, namely: from 250 to 750 cycles; from 750

to 1500 cycles; and from 1500 to 5600 cycles. Typical audiograms of street traffic noise are given in Fig. 15.

From the noise audiograms of a large number of locations on streets of moderate to heavy traffic, the average values of deafening were found to be:

TABLE 4

Band	Average Deafening
250– 750 cycles	51 db
750–1500 "	53 "
1500–5600 "	43 "

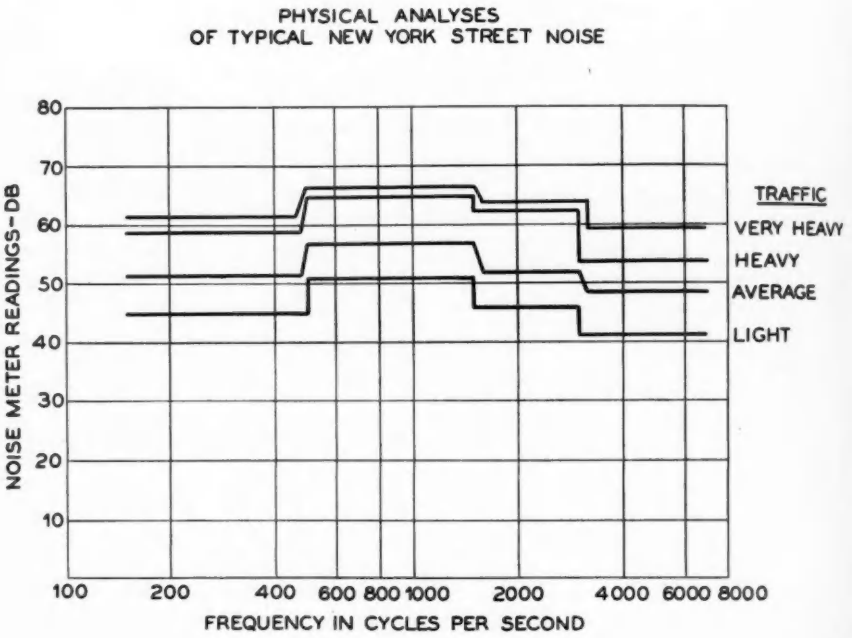


FIG. 14.

The observed deafening in a single band usually varies over a range of about 16 decibels at a given location, in an interval of 10 minutes.

3. *Intensity of Acoustical Traffic Signal*

On the basis of the street noise audiograms, a level in each frequency band may be assigned which a sound must attain in order to be distinctly audible to a person on the street. The sound levels are indicated in Table 5.

TABLE 5

Street Noise	Sound Level in Decibels Required for Distinct Audibility: Frequency Band		
	Low	Middle	High
Average	60	60	50–55
Maximum	75	80	70—75

The figures refer to decibels above threshold. The values for maxima apply to normal conditions; exceptional noise levels, such as that due

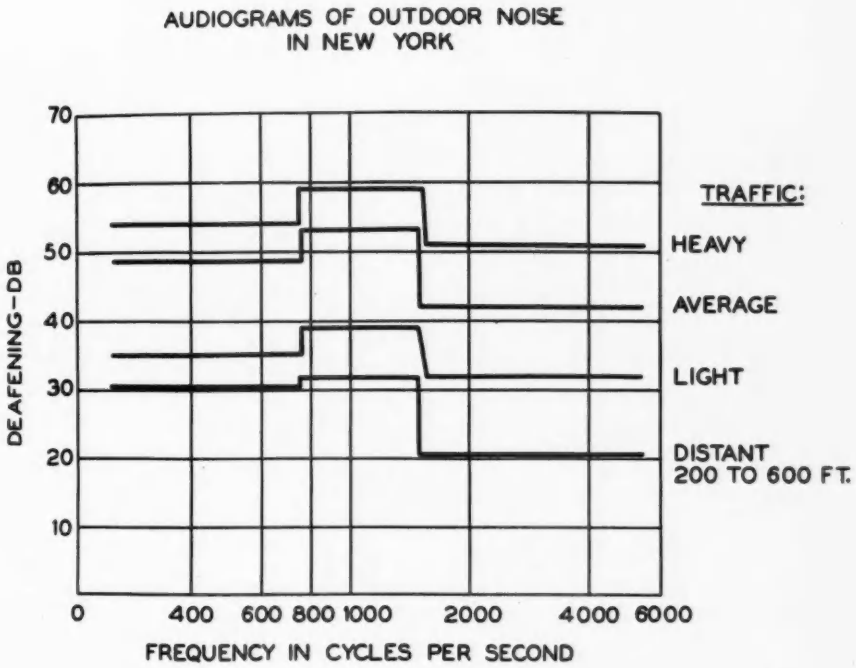


FIG. 15.

to a blast of explosives, may involve still greater levels of sound.

Comparing with these figures the measured level of sound from a policeman's whistle in Table 2 it is evident that no great reduction in intensity is permissible, if the whistle is to be audible in the loudest normal traffic at a distance of 50 to 100 feet.

Tests of automobile horns indicate that certain of the loudest produce unnecessarily great levels of sound.

VI. ANNOYANCE EFFECTS

A test was made to determine whether or not any evident correlation exists between the overall noise level of each specific source and the frequency of complaints against the source, as compiled by Mr. Dennis of the Noise Abatement Commission. It can be definitely stated that the level of the noise is not the sole factor which determines its annoyance as measured by the number of complaints. In a broad way, it does seem that a factor combining level and the frequency of the occurrence is definitely correlated with the annoyance. However, the degree of annoyance seems to depend at least to an equally great extent upon other factors,—possibly the component frequencies and the general character, whether steady or intermittent,—and whether or not the noise is commonly regarded as quite unnecessary, such as the squeaking of brakes of automobiles, or as relatively necessary, such as police whistles. Some idea of the relative frequency of occurrence of the various common noises may be obtained from the observations of the N.A.C. survey of New York. In the last column of Table 2 the number of observations is shown for each of the specific sources mentioned. For those cases involving locations especially chosen to study a particular source, the number of observations is of value principally as an indication of the extensiveness and accuracy of the particular study. For certain common sources, however, the figures in the last column have an added significance; where these figures are marked with an asterisk, the number of observations gives the number of separate instances of definite predominance of the specific noise over all other noises, throughout a considerable part of the survey of New York. In other words, these figures should give some idea of the relative frequency of predominance of the particular noises in the ordinary course of events on the streets of the city. From the standpoint of annoyance, the frequency of predominance must be fairly close to that of occurrence.

VII. CONCLUSION

The sources of the material contained in this paper have already been indicated. In presenting the results of the survey of the Noise Abatement Commission of New York, acknowledgement should be made of the suggestion of Mr. J. S. Parkinson of the Johns-Manville Corporation that a traffic count be made; of the helpful advice of Mr. R. S. Tucker of the American Telephone and Telegraph Co. in regard to the choice of a noise meter and the treatment of results; and of the proposals of Dr. H. Fletcher and Dr. J. C. Steinberg regarding the plan of the survey and the analysis of the data.

JUNE 19, 1930

RESULTS OF NOISE SURVEYS
PART II. NOISE IN BUILDINGS.

By Rexford S. Tucker
American Telephone and Telegraph Co.

Noise experienced indoors is in one sense more important than that experienced outdoors, for, with the growth of our industrial civilization, increasing numbers of people are spending most of their waking hours indoors. They are thus exposed to indoor noise for a large part of the time, including the hours of work when noise has its opportunity to impair their working efficiency.

Certain typical values for noise in various locations in buildings have been published, and will be summarized below. Our knowledge of indoor noise levels is far from complete, however. Further information has been obtained in a survey of room noise in New York City and the surrounding area which was made in 1929 by the National Electric Light Association and the American Telephone and Telegraph Company in the course of the work of their Joint Subcommittee on Development and Research. Some results of the New York City measurements are given herein. About 70 test locations are included. It will be realized that this is only a small sample of the total number of places where indoor noise is experienced in New York City alone. The conclusions given must, therefore, be regarded only as suggestive rather than as holding true in any general sense.

Joint Survey

The methods of measurement employed in this survey were substantially the same as those used in the survey of outdoor noise in New York City described in Part I of this paper. They comprise a three-band audiometer method and a meter method, the noise meter having a thermocouple output and being classed as relatively slow-acting. The results obtained by the meter method are given in the same terms as those obtained with the meter used in the outdoor survey, namely, in terms of noise level. The necessary calibration factor was obtained through simultaneous measurements of several noises by the two noise meters.[1]

The results from the two surveys have been made as directly comparable as possible. Comparisons between them, especially in the case

[1] The noise level was obtained for this meter by adding 25 db to the scale reading on the particular noise meter used.

of the audiometer measurements, are, however, subject to minor errors due to differences between the observers, apparatus, and technique of measurement employed in the two series of tests.

Since the primary object of this survey was to gather information for telephone studies, the noise was measured in each case near a telephone instrument; and in any case where a selection of conditions was necessary, it was endeavored to simulate conditions which would obtain when a telephone call was placed. The noise was taken to include any room sounds which would tend to interfere with telephone conversation.

The measurements reported here were made in the months of January to April.

The results are naturally separated into those for residential and non-residential locations; there is a distinct difference in the general noise level and in the sources of noise in these two kinds of places. About half of the measurements were made in each type of location.

RESIDENCE NOISE

The residential locations visited in New York City were chiefly apartments and generally situated on side streets. The hours of measurement were fairly evenly distributed among morning, afternoon, and evening.

The average of the meter measurements for these residential locations was a noise level of 31 db. The minimum noise level encountered was 22 db.[2] This was found in two places. One was a private residence in a side street in Brooklyn, the noise being due to miscellaneous sounds in the house, to the talk of children on the sidewalk, and to the rustle of the wind, the windows being closed. The other was a hallway on the ground floor of an apartment house on a side street near Central Park, the noise being composed of sounds leaking out from the apartments, street noise contributing a negligible amount. The highest noise level encountered was 45 db; this was found in a room in the rear of an apartment house in Brooklyn, and was due to a pneumatic hammer operating in a nearby street.

This maximum value is just below the lowest average daytime value for any station where measurements were made in the New York Noise Abatement Commission Survey. Though it would, of course, be possible to find higher levels of noise than this in New York homes and lower levels outdoors within the city limits, it can be safely said

[2] Any value given for a particular location is an average for that place.

that the general level of noise of New York streets is much higher than that experienced in New York residences.

The average masking for the residence locations was 16 db on the low-frequency band, 17 db on the middle band, and 12 db on the high band.[3] The masking results show no significant difference in frequency make-up between these residence noises and the street noises measured in the Noise Abatement Commission Survey. The main differences seem to be in the levels and the sources of the noise.

As to the sources of noise, in 20 cases the chief contributing source was indoors (for example, conversation, movement or work going on in the apartment); in 11 cases, it was outdoors (traffic or building construction). Of the highest eight noises, half were due chiefly to indoor sources and half to outdoor sources. Radio sets and sounds coming from adjacent apartments contributed very little of the noise measured in the class of places which were visited.

Noise in Non-Residential Locations

Of the measurements in non-residential locations about one-half were made in offices in downtown New York, about one-fifth were made in factories and workshops, and the rest were made in retail stores and in public buildings such as clubs. Most of the measurements were made in the daytime.

The average of the meter measurements for the non-residential locations was a noise level of 51 db. The minimum noise level encountered was 32 db and was found in a telephone booth in a retail store; only a very few measurements were made in telephone booths. The maximum level, 72 db, was found in a large machine shop; this was due to metal-working machinery and to a man hammering on a sheet of galvanized iron, no major source of noise being as near as 10 feet to the observer.

It will be noted that the average noise level for these locations was 20 db higher than the average residence level. The range of levels is greater for these locations, reaching well up into the range found on New York streets. A comparison of the ranges of levels found in the two surveys is given on Fig. 1.

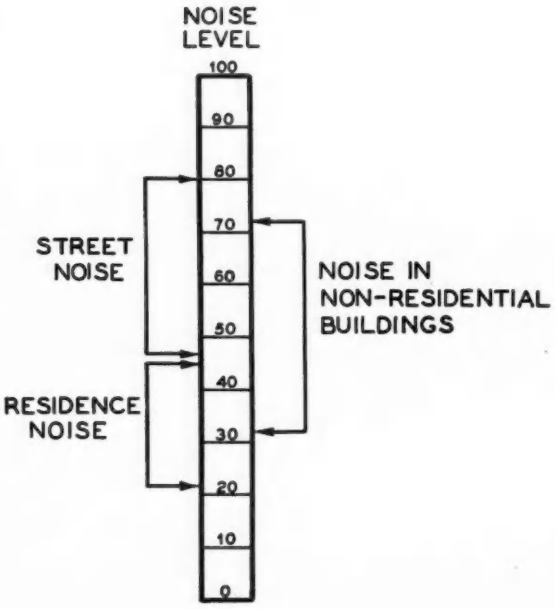
The average masking for the non-residential locations was 37 db on

[3] These figures have been adjusted to the basis employed for the outdoor survey, by making corrections for the difference between the values for threshold of audibility employed in the two cases and for the slight distortion of noise in passing through the slots of the receiver cap. If expressed on the basis employed for the results of the complete indoor survey, published elsewhere, they would be 15, 21 and 12 db, respectively.

the low-frequency band, 41 db on the middle band, and 31 db on the high band.[4]

As in the case of residential locations, the chief sources of noise were located indoors, the predominating source being indoors in 27 cases and

RANGES OF NOISE LEVELS FOUND IN NEW YORK CITY



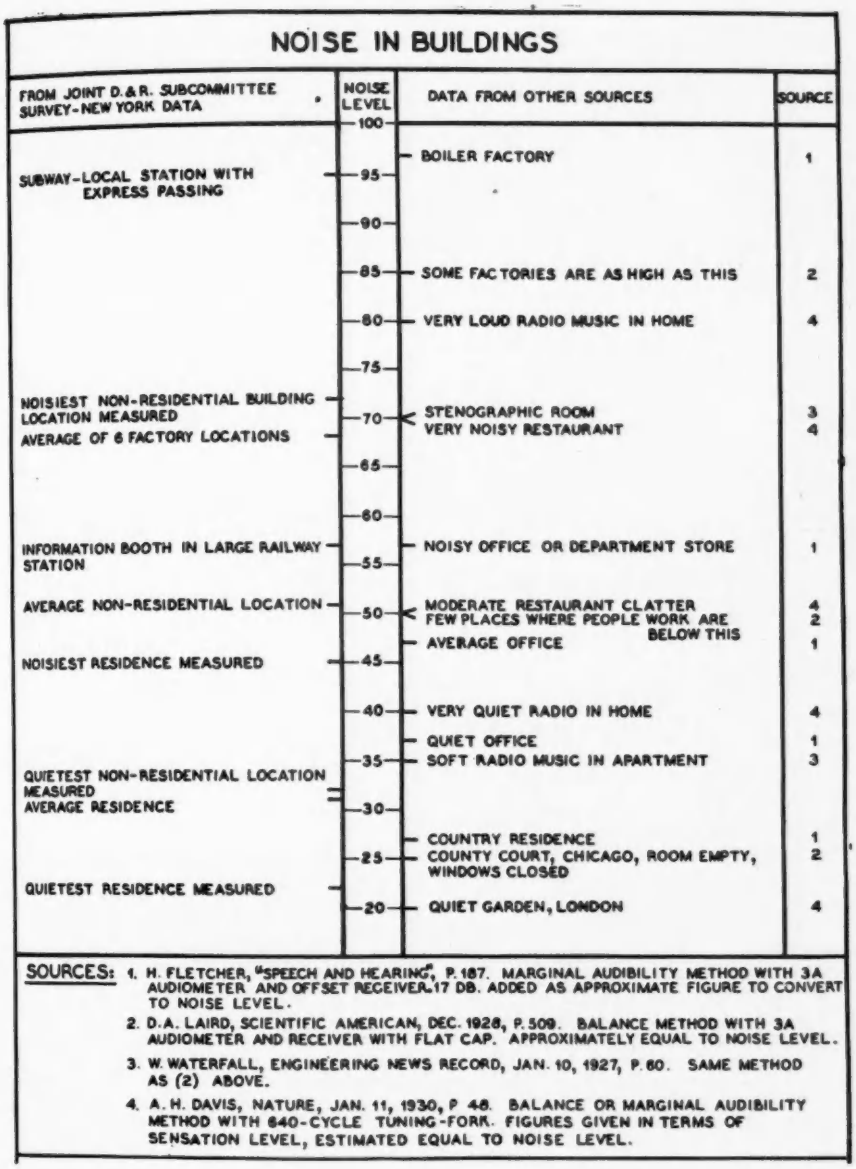
VALUES FOR STREET NOISE FROM NOISE ABATEMENT COMMISSION SURVEY; FOR OTHER NOISES, FROM N.E.L.A.–A.T.&T.CO. SURVEY. ALL VALUES ARE AVERAGES FOR THE LOCATIONS TESTED.

FIG. 1.

outdoors in 12 cases. Practically all of the highest noises were caused mainly by machinery, using this term to include machines in factories, hand-operated tools, and machines used in office work. The noise coming from outdoors was largely due to street traffic.

Some data are available on the differences between noise levels in

[4] Expressed on the basis employed for the complete survey, these figures would be 36, 45 and 32 db, respectively.


NOISE IN BUILDINGS
FROM JOINT D.&R. SUBCOMMITTEE SURVEY-NEW YORK DATA
NOISE LEVEL
DATA FROM OTHER SOURCES
SOURCE
100
95
90
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80
75
70
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55
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25
20
SUBWAY-LOCAL STATION WITH EXPRESS PASSING
NOISIEST NON-RESIDENTIAL BUILDING LOCATION MEASURED
AVERAGE OF 6 FACTORY LOCATIONS
INFORMATION BOOTH IN LARGE RAILWAY STATION
AVERAGE NON-RESIDENTIAL LOCATION
NOISIEST RESIDENCE MEASURED
QUIETEST NON-RESIDENTIAL LOCATION MEASURED
AVERAGE RESIDENCE
QUIETEST RESIDENCE MEASURED
BOILER FACTORY 1
SOME FACTORIES ARE AS HIGH AS THIS 2
VERY LOUD RADIO MUSIC IN HOME 4
STENOGRAPHIC ROOM 3
VERY NOISY RESTAURANT 4
NOISY OFFICE OR DEPARTMENT STORE 1
MODERATE RESTAURANT CLATTER 4
FEW PLACES WHERE PEOPLE WORK ARE BELOW THIS 2
AVERAGE OFFICE 1
VERY QUIET RADIO IN HOME 4
QUIET OFFICE 1
SOFT RADIO MUSIC IN APARTMENT 3
COUNTRY RESIDENCE 1
COUNTY COURT, CHICAGO, ROOM EMPTY, WINDOWS CLOSED 2
QUIET GARDEN, LONDON 4
SOURCES:
1. H. FLETCHER, "SPEECH AND HEARING", P. 187. MARGINAL AUDIBILITY METHOD WITH 3A AUDIOMETER AND OFFSET RECEIVER-17 DB. ADDED AS APPROXIMATE FIGURE TO CONVERT TO NOISE LEVEL.
2. D.A. LAIRD, SCIENTIFIC AMERICAN, DEC. 1928, P. 509. BALANCE METHOD WITH 3A AUDIOMETER AND RECEIVER WITH FLAT CAP. APPROXIMATELY EQUAL TO NOISE LEVEL.
3. W. WATERFALL, ENGINEERING NEWS RECORD, JAN. 10, 1927, P. 60. SAME METHOD AS (2) ABOVE.
4. A. H. DAVIS, NATURE, JAN. 11, 1930, P 48. BALANCE OR MARGINAL AUDIBILITY METHOD WITH 640-CYCLE TUNING-FORK. FIGURES GIVEN IN TERMS OF SENSATION LEVEL, ESTIMATED EQUAL TO NOISE LEVEL.

FIG. 2.

different locations in a single building. Twelve measurements were made in a single office building in downtown New York. In seven of these cases noise from indoor sources predominated, the noise levels ranging between about 35 and 60 db,—over half the total range for all

non-residential locations tested. In the five cases where outdoor noise sources were most prominent, the noise levels ranged between about 40 and 50 db. It will be noted that for this building neither the highest noise levels in the rooms nor the range of noises could be predicted from a study of the noise due to outdoor sources alone. The difference in the noise levels observed was in many cases due to differences in the uses to which these rooms were put, and in some cases was affected by the fact that the windows of rooms exposed to high street noise were opened less than those in other rooms.

RELATION BETWEEN NOISE LEVEL AND MASKING

The difference between noise level and middle-band masking, obtained as an average of the results for residential and non-residential locations, was found to be 12 db. The corresponding figure obtained from the complete room noise survey is 14.5 db. This may be compared with the figure of 14.5 db given in Part I of the paper.

COMPARISON WITH OTHER RESULTS

Fig. 2 gives on the left some noise levels from these New York measurements, and on the right previously published results by other investigators. These have been converted to noise levels by the use of estimated conversion factors as described in the paper on outdoor noise. The fact that the table is not completely consistent may be explained by possible errors in the conversion factors or by the fact that noises in different locations of the same type may differ.

It will be observed that a tremendous range of noise levels is covered by this table, the maximum levels being nearly as high as for outdoor noise.

The available results of studies of noise in homes and places of work are evidently far from complete. More work is desirable along the lines of general surveys, of studies of different classes of locations and of particular noise sources, and of efforts to ameliorate indoor noise.

The author wishes to acknowledge the work of Messrs. J. W. Whittington of the National Electric Light Association and J. M. Barstow of the American Telephone and Telegraph Company in carrying out the joint survey, and the suggestions of Dr. R. H. Galt of the Bell Telephone Laboratories as to presentation of the results.

RESULTS OF NOISE SURVEYS
PART III. VEHICLE NOISES

By John S. Parkinson

Johns-Manville Corporation

The subject of vehicle noise is of interest for a variety of reasons. The preceding discussion will have shown that a very considerable part of the total noise observed both within buildings and in the streets is due various types of transportation vehicles. The study of causes and remedies for vehicle noise therefore becomes of paramount interest in noise survey work.

We are interested first in the noise level as measured within the vehicle itself, and second in the noise level measured outside as the vehicle passes. In other words, we wish to know what noise the rider must endure and also what noise the pedestrian or passerby hears.

Chart 1 gives a table of vehicle noises of various types. The last column gives the measurement expressed in terms of decibels above the

Chart I

Vehicle Noise Chart

Source	Location of Reading	Noise Threshold Shift	Noise Level in Decibels
Airplane	18′ from propeller	103 db.	115 db.
Airplane	In front part of cabin	83 db.	95 db.
Subway Train (express)	Platform of station (local)	—	94 db.
Subway Train	Inside express car	75–80 db.	93 db.
Subway Local	Platform of station	—	88.5 db.
Elevated Train	Street—15 to 75′ away	—	81.5 db.
Elevated Train	Inside car	60 db.	77 db.
Motor Truck	Street—15 to 50′ away	—	73.5 db.
Street Car (over track crossing)	Street—40′ away	—	74 db.
Street Car	Street—15 to 50′ away	—	72.5 db.
Street Car	Inside car	55 db.	72.0 db.
Passenger Auto	Street—15 to 50′ away	—	65.5 db.
Suburban Train	Inside Car	50 db.	67 db.
Limited Train	In Pullman Car	42.1 db.	59 db.

threshold of hearing. Column three gives the noise threshold shift as measured also. In cases where this measurement is shown it has been converted as accurately as possible to give the actual noise level. These

measurements were made, some with the #3-A and the Phonographic Audiometers, and others with the noise meter.

Several interesting facts come to light. The noisiest type of vehicle is, of course, the airplane, and it will be observed that where the measurement is made in such a way that the propeller noise predominates, the noise level approaches very close to the threshold of feeling. The succeeding readings on the table appear very much in the order that the normal observer would expect, with one possible exception. The average deluxe railroad train is considerably quieter than any other form of vehicle listed. It is of interest to note also that there is very little difference in the cases noted between the noise level measured outside the vehicle and inside. It appears therefore that persons near to the point where the vehicle is passing are as much affected by the noise as those riding inside. It is perhaps unfortunate that no measurement was available on the loudness of railroad train noise outside the train. The writer's experience would lead him to believe that this reading would have been considerably higher than the value obtained inside the car.

Chart 2 gives a number of noise level readings made in various parts of a railroad train. These readings are averages of results obtained on a number of different trains on several different roads; all trains were of the so-called "deluxe" type. The readings in every case were made with the 3-A Audiometer. No attempt has been made to convert the

CHART II
READING ON RAILROAD TRAIN NOISE

Location	Speed	Noise Threshold Shift	Remarks
Interior of Pullman	30–35 mi. per hr.	40.4 db.	
" " "	40–50 mi. per hr.	43.1 db.	
" " "	40–50 mi. per hr.	48.6 db.	Window open.
In Dining Car	40–50 mi. per hr.	50.5 db.	Car nearly full.
In Compartment Corridor	60 mi. per hr.	58.0 db.	
On Platform between Cars	60 mi. per hr.	66.4 db.	
Interior of Pullman	60 mi. per hr.	54.0 db.	Passing through town.
" " "	60 mi per hr.	61.0 db.	Passing another train.
" " "	40–50 mi. per hr.	36.5 db.	Berths made up.
" " "	40–50 mi. per hr.	34.5 db.	Inside berth.

Average increase in noise level when train enters tunnel, 12.6 db.
Average increase in noise level produced by opening Pullman Window, 5.1 db.

noise threshold shift values to noise levels, since the readings are of interest primarily for comparative purposes.

It will be noted that there is a fairly good agreement between the noise readings and the speed of the train, the values increasing as the speed increased. The quietest part of the train is, of course, the interior of the pullman car. This becomes even quieter when the berths are made up for sleeping. The peak noise levels were obtained on the platform between cars, or when the train passed another train or a series of cars on a siding. Readings are also included showing the effect of a tunnel in confining and increasing train noise, and the effect of opening a window in a pullman car.

There is a decided difference between the noise level obtained on an ordinary suburban train and that measured on a deluxe train. This difference is no doubt due to the construction and the furnishing of the cars.

There is need for further study in the field of vehicle noises. As has been said, they make up a considerable part of the total noise level in our cities, and any material reduction in the noise which they produce will have a decidedly beneficial effect on the noise level of the city as a whole. There is particular need for thorough study of the noise produced by different makes of the same general type of vehicle. As will be shown later, some work has been done along this line by the street car companies, and Dr. Clyde Snook has studied the same subject with reference to motor trucks.

MAY 21, 1930

RESULTS OF NOISE SURVEYS
PART IV. NOISE REDUCTION

By John S. Parkinson

Johns-Manville Corporation

Methods of noise reduction or elimination are almost as various as the types of noise with which we have to deal. The best that a brief discussion such as this can accomplish is to make a general survey of what has been done, and cite certain instances of actual reductions obtained.

The majority of attempts at noise reduction have been made in offices factories or homes, i.e., where human beings are likely to be affected. Perhaps the most common remedy is to place sound absorbent material in the path of the sound waves. A familiar example is acoustical treatment on the walls or ceilings of offices, banking rooms and the like.

Chart #3 gives a list of rooms in which acoustical treatment was installed with the accompanying reduction in noise level obtained. Where

Chart III

Tests Showing Noise Reduction in Rooms Resulting from Absorbent Treatment

Type of Room	Type of Treatment	Measuring Instrument	Reduction in db.	Calculated Reduction	Percentage Reduction in Intensity
Machine Room Tabulators & Sorters	Sanacoustic Tile entire ceiling.	3A Audiometer	7.9 db. 8.4 db.	5 to 10 db.	83.8% 85.5%
Stenographic Room 5 to 7 Typewriters	Sanacoustic Tile entire ceiling	" "	11.3 db.	" " " "	91.2%
Stenographic Room 6 to 9 Typewriters	1" Acoustical Block entire ceiling	" "	8.9 db.	—	87.0%
Large General Office 150 Machines	Sanacoustic Tile entire ceiling	" "	9.14 db.	9.4 db.	87.8%
School Classroom	½" Fibre Board on furring strips	" "	7.2 db.[1]	—	81%
Weave Room—Large Cotton Mill	¾" Hairfelt	" "	8.5 db.[2]	8.0 db.	85.9%
Cashier's Office	Sanacoustic Tile entire ceiling	Burgess Acoustimeter	6.02 db.	—	75%
General Office Average Size	Sanacoustic Tile entire ceiling	" "	6.4 db.	—	77%

[1] This comparison was made between two similar classrooms—one untreated and one treated.
[2] Half the room was untreated and half treated—the comparison is between the two areas.

this reduction was calculated before hand, this figure is also given. The last column gives the calculated reduction in terms of percentage of intensity, this being the corresponding physical quantity.

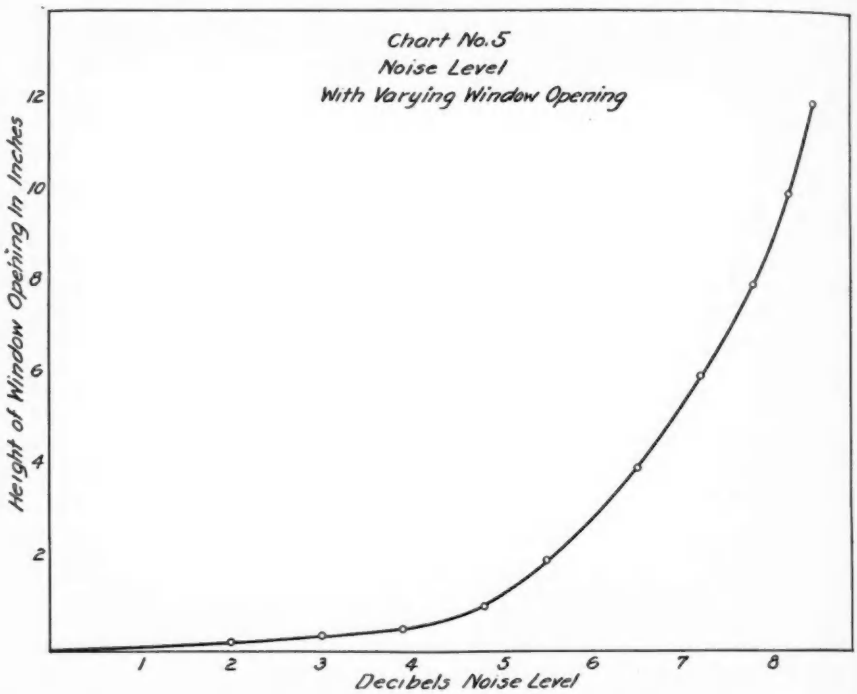
CHART IV

SOUND AMPLITUDE MEASUREMENTS IN CONFERENCE ROOM WITH FELTED CEILING

Window Opening	Position	Reading	Average	Corrected Reading Units	Percent Reduced to
Lower	1	9.0			
	2	10.0			
	3	8.0			
	4	8.0	8.8	(11) .60	43
Lower, middle	1	14			
	2	13			
	3	13			
	4	13	13.3	(12) .92	43
Middle, upper	1	19			
	2	16			
	3	18			
	4	12	16.2	(13) 1.12	46
Lower, middle	1	16			
upper	2	17			
	3	16			
	4	16	16.3	(14) 1.12	41
Lower, middle	1	17			
upper, Ratox	2	18			
Blinds down,	3	14			
Slats horizontal	4	15	16.0	1.10	44
Lower, middle	1	15			
upper, Ratox	2	14	Windy		
Blinds down,	3	16			
Slats sloping outward	4	16	15.3	1.06	40
Lower again	1	8			
	2	11			
	3	8			
	4	8	8.75	.60	37

Microphone calibrated 14 before using and 15 after using.
Corrected reading is average divided by average microphone calibration which is 14.5.
Position 1 is nearest the window, position 4 is farthest away.

The above measurements all dealt with noise generated within the room itself. Prof. F. A. Firestone of the University of Michigan has measured the effectiveness of sound absorbent material installed on the ceiling in reducing the level of noise entering from the street. Chart #4 gives a tabulation of the results thus obtained. The source was a loud-speaker placed on the opposite curb of the street below the window. It will be observed that the sound intensity as measured was reduced to an average of about 43% by the presence of a felted ceiling.



It now becomes of interest to know the effect of windows and window openings upon the noise level measured within a room. (The noise in the experiments following was in every case generated outside the window.)

Chart #5 shows the increase in noise level produced as the height of the window opening in inches is increased. It will be observed that a very small opening is sufficient to allow a large proportion of the noise to enter. This result is in accordance with other experiments on the amount of sound passing through crevices, cracks around doors, etc. Chart #5 is the result of experimental data obtained by Mr. R. F. Norris of the C. F. Burgess Laboratories, Madison, Wisconsin.

Chart #6 gives certain typical readings of the amount of reduction in noise produced by closing the window in an office. The fact that these readings do not check one another closely is due to differences in the noise level within the office and the size of the window opening. They are presented merely as furnishing general information as to the magnitude of this quantity.*

CHART VI

REDUCTION PRODUCED BY WINDOWS

Noise	Location of Pickup	Reduction Produced by Closing Windows
Riveting from across street—2 floors up	4′ inside window Window ½ open	15.0 db.
Riveting from across street—same level	Same	17.0 db.
Street Noise	21″ from window	15.2 db.
" "	21″ " "	21.07 db.
" "	21″ " "	10.0 db.

Several types of window mufflers have been developed whose object was to permit ventilation through the windows without admitting sound from outside. Measurements have been made on some of these, the results being shown in Chart #7.

CHART VII

REDUCTION PRODUCED BY WINDOW MUFFLERS

Noise	Muffling Device	Reduction Measured
Street Noise	Burgess Window Muffler	As efficient as window to .5 db.
" "	Special Baffle Muffler	8.9 db.
" "	Ventilating Baffle	6.5 db.

The Burgess Window Muffler is a device which prevents the sound from entering by lining the air passage with absorbent material. Measurements given are those furnished by the C. F. Burgess Laboratories, who control the patents on this device. The second muffler operates on the principle of a series of glass baffles which reflect the sound outward again into the street, while at the same time they permit air

* For exact laboratory measurements on the reduction factor of windows see the January 1930 issue of this Journal-Paper, "The Transmission of Sound by Walls", by Dr. P. E. Sabine.

and light to enter. It is manufactured by TheWindow Muffler Company of San Francisco, Calif.

For purposes of comparison a measurement is also given on the amount of noise reduction produced by an ordinary ventilating baffle set inside the window opening. This baffle was of a familiar form, about 10″ high and set on the window sill at an angle of about 30 degrees from the vertical. It is probable that, had this baffle been set outside the window, the noise reduction measured might have been even greater. There is no data available on this.

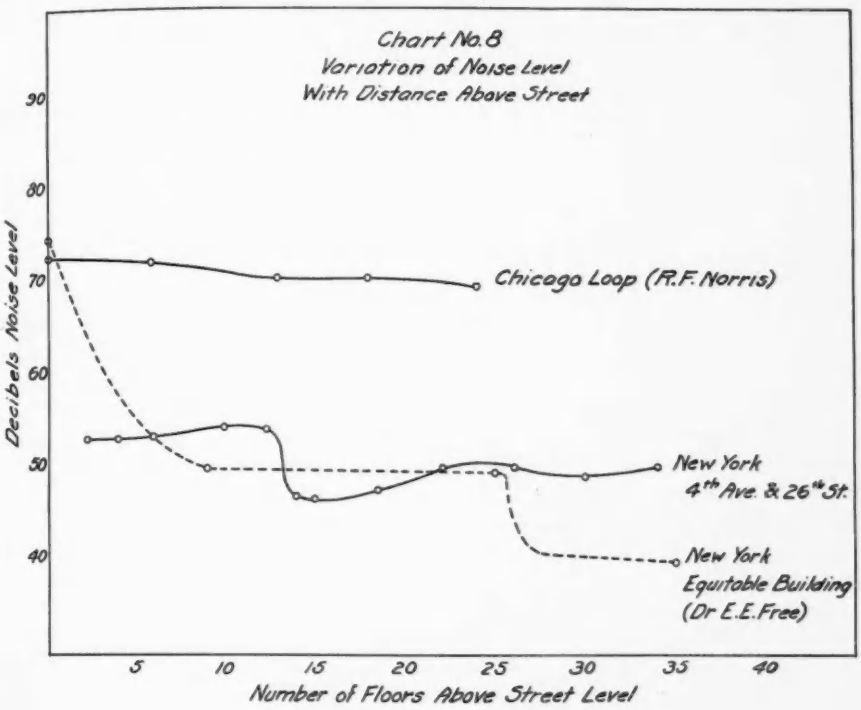
Sound absorbent material is used in a variety of other ways for purposes of noise reduction. Among these may be mentioned the lining of ducts, and the insulating of partitions, walls, floors, etc. There is no exact data available on the effect of lining ventilating ducts. The Carrier Engineering Corporation, however, has conducted a series of tests on this subject, and they report that they have been able to measure a very definite reduction by the use of special sound absorbing constructions placed in the ducts. They have been able to reduce the sound level as measured in the room in question to levels as low as 8 or 10 db. above threshold. They estimate the ordinary noise level, when no sound absorbent material is used, to be as high in some cases as 30 or 35 db. It is apparent, therefore, that a very marked reduction can be obtained.

The subject of sound insulating partitions has been covered in other publications of the Society and will not be dealt with here.

One other set of experiments is of interest in the discussion of methods of noise reduction. These experiments deal with noise levels at different distances above the street. Chart #8 gives the results of three such surveys, one made in the Loop District of Chicago by Mr. R. F. Norris, another made at the Equitable Building in New York by Dr. E. E. Free, and a third made at the New York Life Building by the writer.

The survey made at the New York Life Building indicated that, until the height of the surrounding buildings had been passed, there was no marked change in the noise level observed. The surrounding buildings were from nine to thirteen stories in height. From that point on as the distance above the street increased the noise levels were decidedly lower, the lowest one being obtained opposite the setback on the fourteenth floor. Observation indicated that the setback acted as a baffle and prevented the noise, which came largely from below, from reaching the windows at this level. It will be noted from the chart that, as the distance above the setback increased, the effect was not so marked. There was a similar effect at higher setbacks, but not sufficiently marked to

produce any particular change in the form of the curve. As a matter of fact the character of the noise above the fourteenth floor changed very decidedly. Below this level it was composed largely of noises rising from the streets immediately below. Above this level it consisted of the general noises of the city, being a combination of elevated train noises in the distance, harbor noises, and a general hum of traffic noise. It will be noted that the thirty-fourth floor was no quieter than the floors below. Unfortunately, no information is available to indicate



how high above the street it would be necessary to go before the noise level began to decrease.

Certain measurements have been made dealing with miscellaneous types of noise reduction other than those discussed. These do not fall under any general classification, and are presented merely as belonging to this general subject. It has been shown, for example, that the difference between the average noise of an elevated passing over a steel structure and over a reinforced concrete structure is about 10 db.; the reinforced concrete structure, of course, being the quieter.

The Interborough Rapid Transit Company of New York succeeded in producing a 12 db. reduction in the noise of their turnstiles by making certain mechanical changes and providing rubber stoppers instead of metal ones. (This measurement was made on only one bank, and is probably subject to correction when more data is available.)

The American Street Railway Association in one of its committee reports states that it was possible to reduce the overall noise in a street car 47% by using special resilient wheels, padding the floor and gear box with a felt, insulating the trolley base, using new gears, etc. This measurement is in terms of sound energy. The same precautions produced an overall noise reduction at the curb of 18% for this car.

SOME NEW INSTRUMENTS IN THE IOWA LABORATORY FOR THE PSYCHOLOGY OF MUSIC

By C. E. Seashore
University of Iowa

To physicists a brief indication of the character of the problems that present themselves in the Psychology of Music may be of greater interest than the description of instruments. I would, therefore, indicate something of the general scope and nature of our problems in terms of certain fundamental principles which we have derived on the basis of experimental evidence.

1. All that is conveyed from musician to listener as music is conveyed on the sound wave. Therefore, the recording and analysis of the sound wave should furnish an objective medium for the analysis of musical performance.

2. All musical performance may be expressed in terms of four media: the tonal, the dynamic, the temporal, and the qualitative; in psychological terms, pitch, intensity, duration, and timbre, each in turn measurable in terms of frequency, amplitude, duration, and form of sound waves.

3. The medium of musical art lies primarily in artistic *deviation* from the fixed and regular; such as rigid pitch, uniform intensity, fixed rhythm, or pure tone. The quantitative measurement of performance may, therefore, be expressed in terms of measurement of these deviations in each of the four groups of attributes.

4. For each of these measurements we have the equivalent of a zero starting point, which makes measurements comparable. Thus, for pitch, it is the frequency of the standard tone, for intensity, it may be physical absence of sound, for duration, the prevailing tempo, and for timbre, the pure tone.

5. Successful musical performance rests upon the mastery of the above four groups of fundamental skills, which may be isolated and acquired as specific habits.

6. In musical training these fundamental skills should be acquired by instrumental aids, visualizing the tone; that is, training the ear by the eye in order to hasten the development of each skill and insure a higher degree of precision than is ordinarily attained without instrumental aid.

7. For the purpose of evaluating musical performance and setting

up goals of attainment, norms of artistic singing and playing are being set up in terms of the measurable factors in performance.

8. The aesthetic principles of musical art may be formulated and classified on the basis of measured performance, treating the data collected in an objective manner.

9. A scientific musical scale, called a pattern scale, has been designed so that the results of measurements of primitive or artistic music may be expressed in a graphic manner upon a staff that has musical significance.

From each of these points of view, it is evident that there is great demand for new instruments to meet the needs indicated. Among the instruments recently devised in the Iowa Laboratory are the following:

1. *The Piano Camera.* This camera is described by Tiffin and Seashore in a current number of "Science" (probably June 1930). It photographs the action of piano hammers under normal conditions of playing, so that for an entire musical selection we may have a time and intensity record for a complete analysis of rhythmic performance. The time is recorded by showing the exact moment at which the hammer strikes the string and the intensity in terms of duration of the movement of the hammer through the last twelve millimeters of the stroke. The record is made on a 4″ paper film. The camera is located about three feet vertically above the upright piano. A bank of lamps just over the keyboard is covered by a milk glass. A light paper tailpiece is glued with one end on the top of each hammer, the other end rests on the milk glass. The movement of the hammer carries this tail piece which has a suitable slit through which the light records the stroke. A flashing neon light sets up a time line across the whole film and the key that is played is identified by a 4″ scale which may be laid across the record in reading.

Tiffin and Metfessel have substituted a mercury vapor lamp (described in the American Journal of Psychology, probably the July, 1930 number) and Reger has added a frequency line to serve as a means of identifying the pitch of the fundamental tone. This camera has an extraordinary range of usefulness in that it graphs the time and pitch factors of a solo voice or instrument or of a speech or any other fairly simple sound directly and, therefore, is an enormous time-saving device both in the recording from nature and in transcribing from records or other sound producing instruments.

3. *The new synthetic vibrato apparatus*, described by Tiffin in a cur-

rent number of "Science" (July 19, 1929), furnishes a means of presenting the vibrato of a pure tone in all its significant aspects. It utilizes the principle of the photoelectric cell, the light being interrupted by a siren in which the frequency is determined by the spacing of holes and the intensity by the size of the holes.

4. *Rhythm meter*, first described by R. H. Seashore in the University of Iowa Studies in Psychology Number IX and later modified in the Iowa Laboratory, is a means of recording rhythmic performance for measurement or for practice. The instrument sets up a rhythmic pattern with which the subject has to keep time, marking the time with a key. The record is graphic and is of such a nature that a person who is training may see at any moment the character of error he makes.

5. *The tone dynometer* is a means of measuring precision in musical touch. It is a loud speaking audiometer in which the experimenter produces a tone which rises quickly to a given intensity and the subject is required to match this by responding on a suitable lever.

6. *The new model of the tonoscope* (Model VI) just described in University of Iowa Studies, "The Measurement of Pitch Intonation with the Tonoscope in Singing and Playing," is portable and adaptable for general laboratory and studio use. It consists of the stroboscopic screen in the form of a drum. A tone is picked up by a microphone and amplified and delivered through a neon light which illuminates the moving screen. A scale enables the observer to read the pitch of the tone directly. Depending upon the degree of steadiness of the tone, the reading may be made in terms of tenths, twentieths, or hundredths of a tone. The instrument has reliable speed control, furnishes the key note by induction from a wheel on the drum itself, and has a record-carrying device on which standards for reproduction may be reproduced from a phonograph record.

THE REVERBERATION TIME BRIDGE

An Instrumental Method for Measuring Reverberation Time

By Harry F. Olson and Barton Kreuzer
RCA Photophone, Inc.

The measurement of the reverberation time (i.e. time for sound energy to decay over a ratio of a 1,000,000 to 1) of large rooms, halls, studio sets, theatres, etc., has been attempted by various means. The simpler of these schemes involves a personal equation, together with the possible inaccuracies of original calibrations.

The more satisfactory methods employ more complex equipment, usually not portable, and depending upon fairly intricate mechanical adjustments and often subject to the delay and inconvenience of photographic apparatus or timing mechanisms.

The bridge which we propose is portable, accurate, can be used for rapid routine testing, and has a minimum personal equation error.

If we assume the logarithmic decay of well mixed sound in a room (later we shall concern ourselves with deviations in actual practice) we have the equation for the sound energy during the decay period.

$$E = E_0 \epsilon^{-t/k} \tag{1}$$

where E = sound energy density at any time after sound source is cut off.

E_0 = sound energy density while source is radiating and steady state conditions have been established.

k = constant for any room dependent upon the volume, bounding surfaces and the absorption coefficient of the latter.

t = time in seconds.

If the equation deals with sound pressure (this may be measured more conveniently) instead of energy, the expression is of the same form as (1) but the reverberation time is determined by a decay ratio of the pressures of 1000 to 1 since sound energy is proportional to the square of sound pressure.

Now, the equation for the voltage across a resistor into which a capacitor is being discharged is

$$V = V_0 \epsilon^{-t/RC} \tag{2}$$

where V = voltage any time "t" after discharge starts

V_0 = voltage across capacitor terminals before discharge
R = value of resistor
C = value of capacitor

The analogy between equation (1) and (2) is immediately apparent and is the basis of our bridge. The idea is essentially this: If the pressure of the decaying sound can be measured and compared with the voltage across a resistor into which a capacitor is discharging, by adjusting the constants of the electrical circuit so that the rate of decay for both room and circuit are equal, then the times for both curves to fall through a given decrement (the 1000 to 1 value, defining reverberation time) are equal. With this knowledge the reverberation time is equal to the value of "t" in the "time constant" of the electrical circuit, which may be easily calculated.

The apparatus, as built and used, consists of a condenser microphone for measuring the sound pressure. The output of the microphone is amplified by a high quality audio frequency amplifier, part of which is housed in a "bullet" in the conventional manner and the rest of which, including a gain control is built into the bridge proper. The output of the amplifier is fed to a practically linear vacuum tube voltmeter with a panel mounting meter.

A capacitor connected to a discharging resistor is so arranged that its charging battery is disconnected by the same panel mounted switch that disconnects a loudspeaker from an oscillator. It is apparent that the loudspeaker (driven from the oscillator) is the sound source for the measurement.

The voltage across the discharging resistor is measured by another practically linear vacuum tube voltmeter, adjusted to have a duplicate of the characteristic of the first vacuum tube voltmeter.

The two voltages are compared accurately by the simple expedient of using a zero center galvanometer common to the plate circuits of both vacuum tubes.

When the variable discharging resistor is adjusted so that the galvanometer indicates zero during the decay period, the value of "t" in the "time constant" of the electric circuit is then the actual reverberation time, since the characteristics of the two vacuum tube voltmeters are the same

If the constants of the electric circuit are appropriately chosen the variable discharge resistor may be marked off directly into seconds and fractions of a second, and the reverberation time read immediately after the bridge has been balanced.

The circuit diagram is shown in Fig. 1. This does not include the "bullet" amplifier, oscillator, or loudspeaker. The outfit is portable, employing tubes and circuits requiring low voltage supply and consuming small current.

Fig. 2 shows the calibration curves for the two voltmeters. Relative linearity is obtained by using large grid swings, grid resistors, and driv-

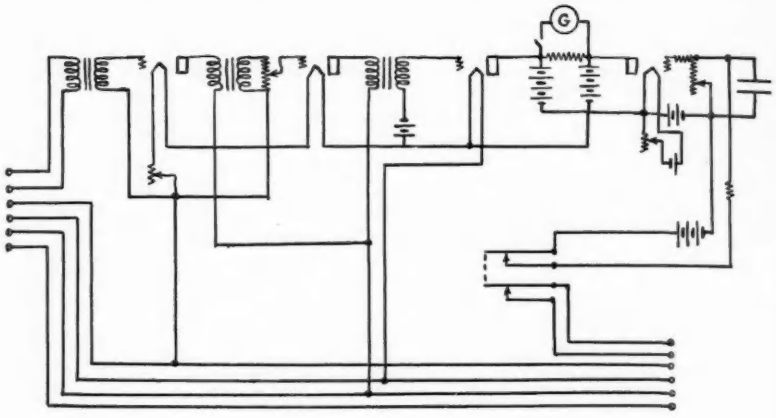


FIG. 1. *Circuit Diagram.*

ing the grids positive, allowing them to draw grid current. It may be remarked here that this drain is negligible compared to the current through the discharging resistor.

The characteristics of the two voltmeters were made identical by the adjustment of grid resistors. The advantage of linear voltmeters over the square law type lies in the fact that the accuracy of comparison over the entire range is constant, i.e. no one part is exaggerated with respect to another.

In operation the charging voltage for the capacitor is fixed at a value to insure full scale deflection on the d.c. vacuum tube voltmeter. The steady state sound pressure is now being measured by the microphone and associated apparatus. By manipulation of the gain control, enough voltage is supplied to the a.c. vacuum tube voltmeter to restore the common meter to its zero center.

A switch is now operated which disconnects the charging battery from the capacitor and simultaneously shuts off the sound source. The "decay" period for both the sound and the electrical circuit have now begun and it is a simple matter to vary the value of the discharging

resistor until a null reading is maintained during the decay period. Reverberation time is then read directly from the calibrated resistor.

In the case of rooms where the sound cannot be assumed to be thoroughly mixed or where due to predominating individual reflections, the

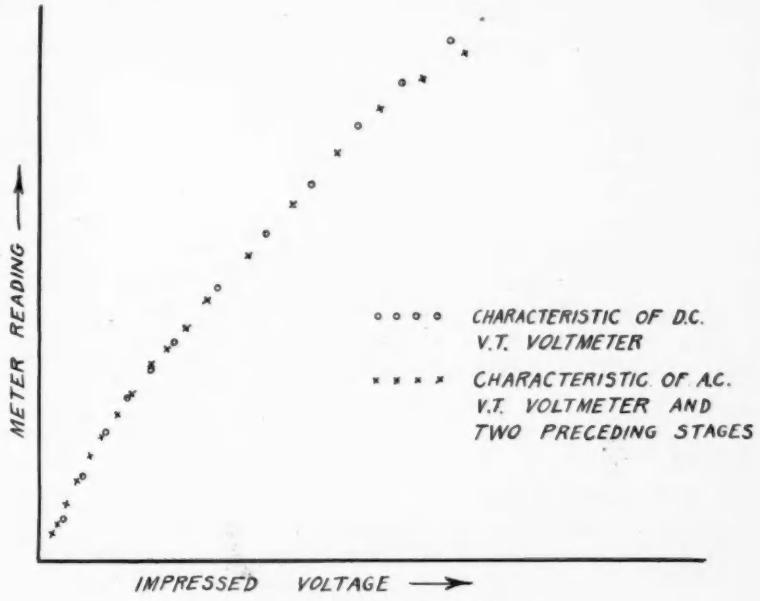

METER READING
IMPRESSED VOLTAGE
CHARACTERISTIC OF D.C. V.T. VOLTMETER
CHARACTERISTIC OF A.C. V.T. VOLTMETER AND TWO PRECEDING STAGES

FIG. 2. *Calibration Curves of Voltmeters.*

decay curve varies about the logarithmic one as a mean, with a small amount of practice the observer can quickly strike a mean value, relying chiefly upon the balance at the bottom of the curve where the variations from the mean are smaller.

It is understood that the microphone and loudspeaker are so located that the ratio of direct to reflected sound at the microphone is very small. This is ordinarily the situation in any room where the source is placed at a reasonable distance from the microphone.

In special cases, such as exceptionally well damped rooms, where it is conceivable that the ratio of direct to reflected sound might not be a negligible factor, the procedure of making a measurement should be slightly altered.

Instead of balancing the steady state electrical condition against the steady state sound value, the curves should be matched entirely during the decay period. This means manipulation of the gain control as well

as the discharge resistor, but should not prove difficult. Cases of this type, however, are relatively rare.

As is rather well known, the possibility of error due to standing waves may be considerably reduced by employing a wobble frequency for the sound source.

If, for any other reason it is desired to make an observation using only a portion of the decay curve, the normal procedure is followed, but by means of a separate switch, the meter is held out of the circuit (after the steady state adjustment has been made) until that portion of the decay is arrived at where it is desired to begin the comparison.

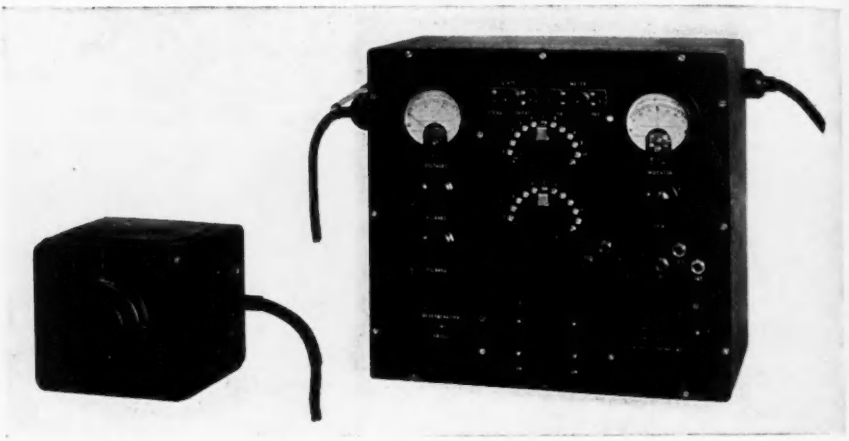


FIG. 3

It is apparent that modification of this particular design for special purposes is comparatively simple. The sensitivity and range of the vacuum tube voltmeters may be increased or they may have two or more ranges with a quick changeover switch. Additional sound level may also be used, if the charging voltage for the capacitor is increased proportionally.

It is obvious, also, that a similar bridge may be very easily constructed to measure the time for growth of sound.

As can be seen from Fig. 3, the device is really compact, portable, with a minimum of controls and because it is a visual, null, bridge method reduces the personal equation error to a minimum.

MASKING EFFECTS OF AN INTERFERING TONE UPON A DEAFENED EAR

By

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and

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While the masking effects of one tone upon another, such as is exemplified in the experiments of Wegel and Lane,[1] have been studied extensively in recent years by means of the oscillating vacuum tube principle, there seems to have been much less attention given to like experiments with deafened people. Preliminary tests by the authors[2] of this paper showed that the magnitude of the diminished sensation of one tone in the presence of another loud tone was different in *normal* and in deafened ears. The object of the present series of experiments was to secure more information on the masking function of deafened ears by means of two tones.

Apparatus, Procedure and Summary of Results

Two oscillators with amplifiers, attenuators, and impedance adjusting transformers were coupled to an "off-set" telephone receiver as shown diagrammatically in Fig. 1. The "off-set" receiver was kept at a constant distance of about 0.5 inches from the head by means of a horseshoe-shaped frame in order to minimize the change of threshold due to increase of pressure of the receiver against the ear. This change of threshold is markedly noticeable at the higher frequencies. The tone which was used for masking purposes was called the interfering tone. The threshold of this tone was obtained and then it was raised to 50 db above the threshold for each person examined. The tone which was heard in the presence of the interfering tone of 50 decibels (abbreviated as db) will be referred to as the primary tone. If the threshold of the primary tone above that of the "normal" is designated as S_0 and the threshold of the primary above the "normal" in the presence of the interfering tone is called S_1, then the masking effect of the interfering tone is the difference of the above thresholds, i.e., S_1-S_0. We have called this difference (S_1-S_0) the differential threshold. An H network with grounded center tap, calibrated to 110 db, was used to obtain these differences.

[1] Phys. Rev. 23, pp. 266–285, Feb. 1924.

[2] Phys. Rev. 31, p. 712, April 1928.

The interfering tone used in most of the work was 360 cycles/sec. The magnitude of harmonics in this tone were not estimated, but found to be hardly noticeable when viewed with a General Radio String Oscillograph, Type 338. The primary tones of 300, 510, 810, 1700 and 2800 cycles/sec, approximately, were obtained by means of a General Radio Low Frequency Oscillator, Type 377.

The threshold of a tone in every instance was found as follows: introduce sufficent intensity of the tone so that the patient may familiarize himself with the tone he is expected to hear at his threshold, then reduce it below threshold, and finally increase the intensity until it is just heard.

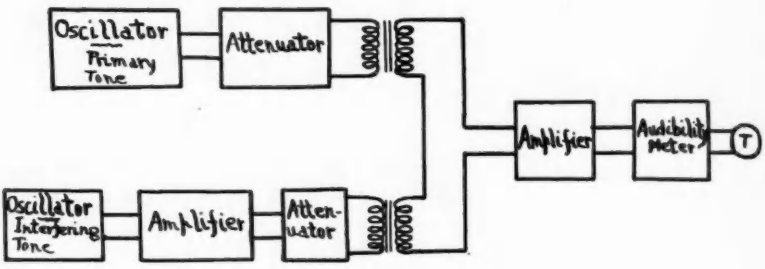


FIG. 1. *Apparatus.*

The results of these experiments may be summarized in the following way:

1. The differential threshold (S_1-S_0) is less in a deafened than in a normal ear in the presence of an interfering or masking tone of the same energy level above threshold (50 db). The thresholds refer to the one examined in each case.

2. The above finding is true in the so-called conduction as well as in perception deafness. In conduction deafness the above mentioned finding may be more pronounced.

3. The differential thresholds become smaller with increasing deafness.

EXPERIMENTAL DATA—MODERATE DEAFNESS

For tabulation purposes, we classified our cases of deafness as perception deafness, conduction deafness, and deafness of a mixed nature. This classification is tentative, for it is very difficult in many instances to draw sharp lines in the clinical examinations of these cases. In fact, there are those who doubt whether definite sharp differentiations in this respect can be made at all.

In order to show the general nature of the decrease in the differential thresholds ($D=S_1-S_0$) with increasing deafness (S_0) in the primary a representative set of data is shown in Fig. 2 with a primary tone of

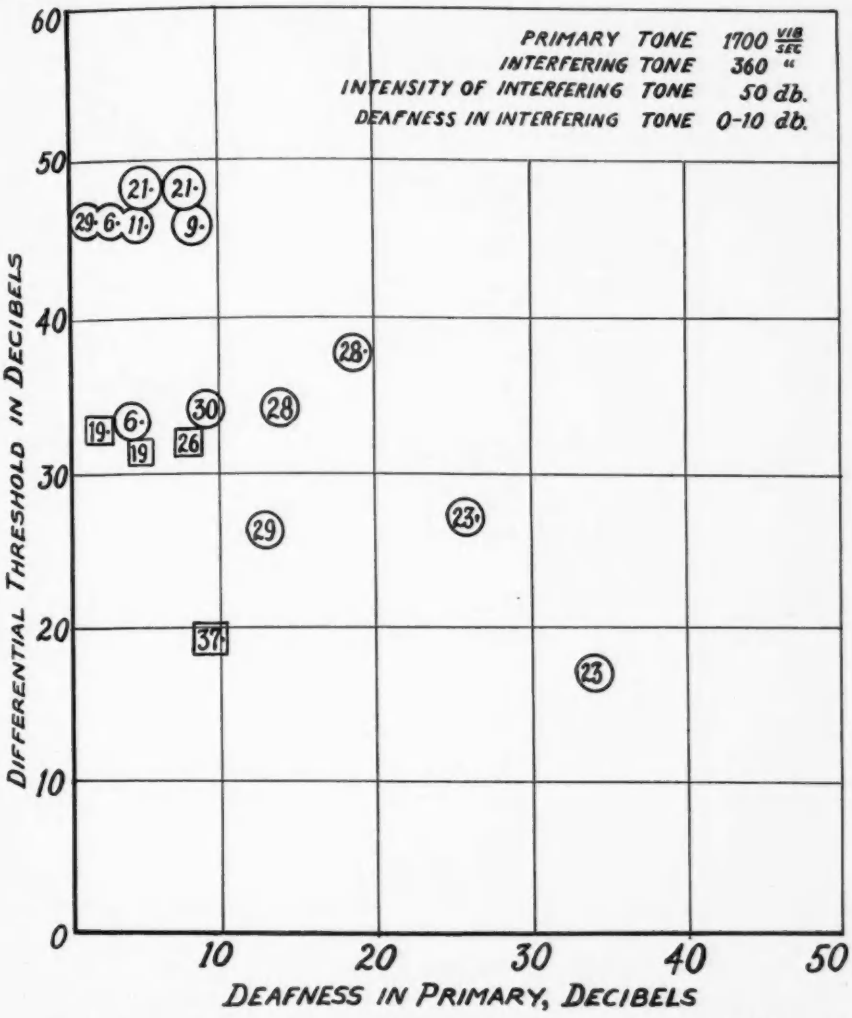


FIG. 2. *Centers of figures represent points indicating the manner in which the differential threshold of the primary decreases for increasing degrees of deafness in the primary. The numbers refer to the case.*

1700 cycles/sec. and with deafness of from 0–10 db in the interfering tone. In this figure, the differential thresholds (D) in db are plotted as ordinates against deafness (S_0) in the primary in db. This gives us a number of points, each point being represented by a number. The

numbers refer to the case while the dot to the right of certain numbers indicates that it is the right ear. Positions on the graph representing perception deafness are represented by having the case numbers inclosed in circles, while those representing conduction deafness are enclosed in squares.

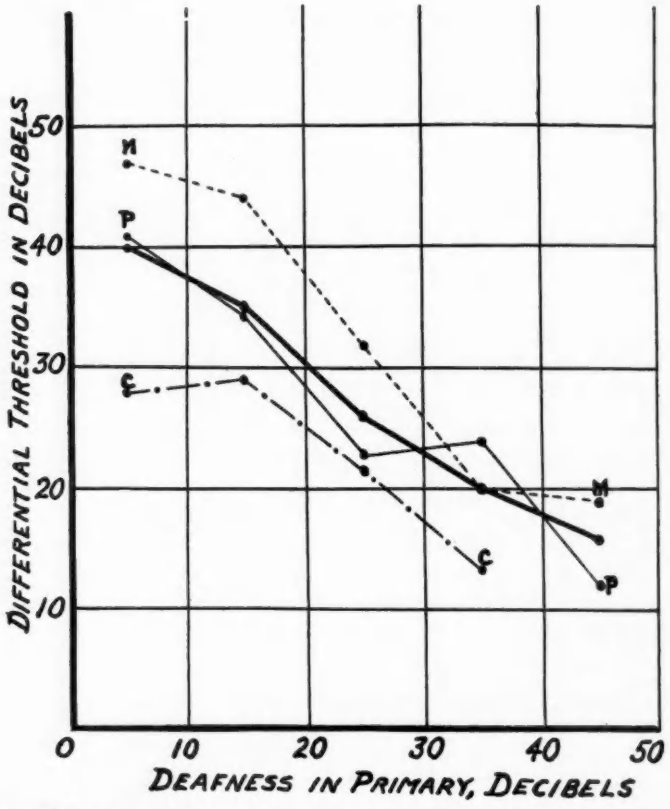


FIG. 3. *Differential thresholds for frequencies 810, 1700 and 2800 averaged and plotted against degrees of deafness.*

While the differential thresholds are seen to decrease with increasing deafness in the primary, the variation from case to case is very marked. We were looking in particular for some difference in the magnitude of the differential thresholds between conduction and perception deafness. In Fig. 2 there appears to be some tendency for the differential thresholds for conduction cases to be less than those for perceptive cases. In order to study this point further, a statistical curve (Fig. 3) was drawn showing the relation between the average differential threshold and the degree of deafness. To get a fairly representative number of

points, the average value of the differential threshold for the tones 810, 1700, and 2800 were recorded for intervals of increasing deafness in steps of 10 db. These three frequencies were chosen because the differential thresholds in each case were nearly the same for the same degree of deafness in the primary. No attention was given to differences in thresholds of the interfering tone in drawing this curve, since we found by a study of all charts that the thresholds of the interfering tone had but little, if any, effect on the results for the differential thresholds.

It will be noted that the curves in Fig. 3 tend to lie at different levels in the order "mixture," "perception," and "conduction," the latter being at the lowest level. The heavy continuous line is the average of the three curves mentioned above. It is not clear why the average level for "mixtures" cases should be at the highest level if the difference in level between the conduction and perception curve is a true effect. It should be mentioned, however, that our "mixture" cases were few in number compared to the others mentioned.

Results for typical individual cases are plotted in Figs. 4a, 4b, and 4c, giving threshold values for the primary frequencies and the corresponding differential thresholds. On each curve are found the results obtained from the examination of two ears.

The curves, marked at each end by the symbol S_0', represent the deafness in the primary tone for the person whose case number is found on the curve (R stands for "the right ear"). The symbol D' is associated with the curve representing the differential thresholds for the person whose primary deafness is given by the curve identified with the letter S_0'. Similar remarks may be made concerning the symbols S_0'' and D''. Straight lines are drawn between the points for convenience only. Taking the two conduction and the two perception cases by themselves, a similarity in variations of deafness and differential thresholds with frequency will be noticed. The differential threshold for the "normal" is shown in Fig. 4d. This "normal" was found as a result of about 10 examinations.

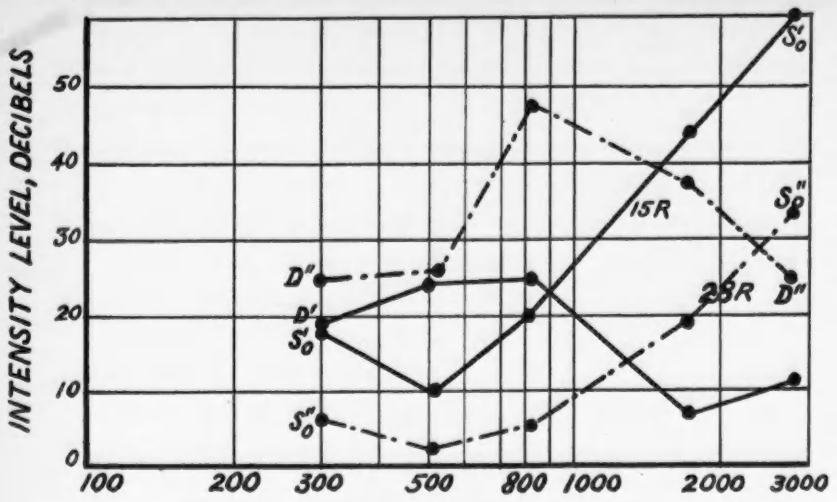
Table 1, with its condensed summary of certain clinical examinations with experimental data, illustrates briefly the method of classification for our cases. The deafness in the primary of each tone is represented by S_0 (measured in db) and the differential threshold by D. Note that the threshold of the primary in db in the presence of the interfering tone will be obtained by the addition, S_0+D. In the clinical examinations, the figures above the division line refer to the right ear while those below, refer to the left. Where two figures appear, either above or below

TABLE I.

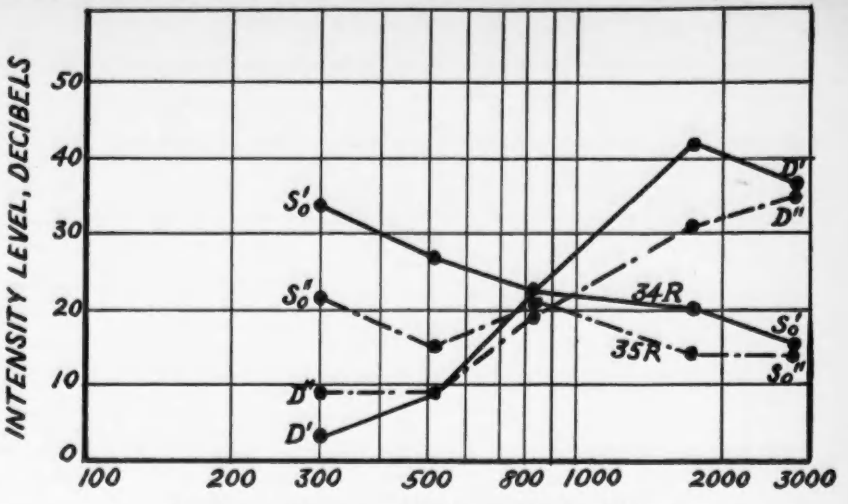
			"Perception" Deafness						"Conduction" Deafness						"Mixtures"					
Case			1		15		21	23	28		13	34		35	37		5		9		10	
Ear			R		R	L	L	R	R		R	R	L	R	L		R	L	R	L	R	L
Primary Frequencies	300	S_0			18	14	2	9	7		35	34	34	21	20				10	22	26	20
		D			19	8	20	18	25		9	3	0	9	10				32	34	14	18
	510	S_0	12		10	9	1	6	2		35	27	21	15	24		27	42	11	12	23	11
		D	34		24	13	24	21	26		9	9	6	9	8		11	5	25	29	11	22
	810	S_0	20		20	21	7	15	5		31	22	20	22	26		30	42	22	20	30	23
		D	31		25	19	46	36	48		23	22	24	20	10		24	15	33	35	36	38
	1700	S_0	34		44	29	5	26	19		25	20	23	14	19		11	20	8	3	31	28
		D	25		7	14	47	27	38		38	42	34	31	27		54	35	47	52	30	31
	2800	S_0	50		60	48	15	38	33		18	15	28	15	22		24	41	17	11	58	51
		D	4		11	10	34	18	25		50	37	36	36	24		41	25	41	47	15	22
	360	S_0			14	15	7	9	3		32	25	26	14	20				7	12	30	16
Voice			$\frac{20+}{20+}$		$\frac{5-20+}{10-20+}$		$\frac{20+}{20+}$	$\frac{1}{3}$	$\frac{10-3}{8}$		$\frac{6}{0-\frac{1}{2}}$	$\frac{3-5}{10-5}$		$\frac{1-20+?}{20+}$	$\frac{20+}{15}$		$\frac{20+}{5-6}$		$\frac{20+}{20+}$		$\frac{\frac{1}{2}-20}{20+}$	
Whisper			$\frac{20-10}{20-10}$		$\frac{5-3}{5}$		$\frac{20+}{20+}$	$\frac{\frac{1}{2}}{\frac{1}{4}}$	$\frac{2-1}{3-6}$		$\frac{\frac{1}{4}}{-}$	$\frac{0-\frac{1}{4}}{\frac{1}{2}}$		$\frac{\frac{1}{2}}{20+}$	$\frac{20}{\frac{1}{2}}$		$\frac{15-1}{5-\frac{1}{2}}$		$\frac{20+}{20+}$		$\frac{\frac{1}{2}}{\frac{1}{2}}$	
Weber			? —		? —		— —	? —	? —		R —	? —		R —	— L		? —		? —		R —	
Rine			$\frac{+}{+}$		$\frac{+}{+}$		$\frac{+}{+}$	$\frac{+}{+}$	$\frac{+}{+}$		$\frac{-}{-}$	$\frac{-}{-}$		$\frac{-}{+-}$	$\frac{+-}{-}$		$\frac{-}{-}$		$\frac{+}{+}$		$\frac{+}{+}$	
Sch.			$\frac{?}{?}$		$\frac{n}{n}$		$\frac{n?}{n?}$	$\frac{?}{?}$	$\frac{-10'}{-10}$		$\frac{+10}{+10}$	$\frac{+10}{+15}$		$\frac{+16'}{+10'}$	$\frac{+12}{+12}$		$\frac{n}{n}$		$\frac{-5}{-5}$		$\frac{+15}{+12}$	
C_4			$\frac{+5'}{+5'}$		$\frac{-18}{-15}$		$\frac{+5}{+15?}$	$\frac{-10}{-15}$	$\frac{-10}{-7}$		$\frac{-7'}{-7}$	$\frac{-10}{-12}$		$\frac{-10?}{n}$	$\frac{+7}{-5}$		$\frac{-6}{-6}$		$\frac{n}{n}$		$\frac{-7}{+5}$	
Diagnosis			Lues? Vestibular nerve normal.		Tinnitus. Telephone operator.		Lues. Spont. nystagmus. Spont. dist. of equilibrium. Induced reaction normal. int., normal.	Lues Hypersen. Vest. nerve. L. mt. small (lentil size) opacity in incostapedio region.	Lues Vertigo Tympanic membrane normal.		OMPC. for 30 yrs. in L. and 7 yrs. in R. Mast. on L. 29 yrs. ago. Rad. Mast. on R. in 1929.	OMPC last 2 days. Spontan. perfor. Irrigated before exam.		OMC Subac. Discharging last 10 wks.	OMC Subac. for 2 wks. Aches occasionally.		Otoscl. Tinnitus mostly left Heredity		Nerve? Some disturbance of vestibular reaction.		Cond.? OMPC both Rad. Mast. 7 mths. ago.	

Frequency of Primary. (c) Two "Mixtures." Frequency of Primary. (d) "Normal."

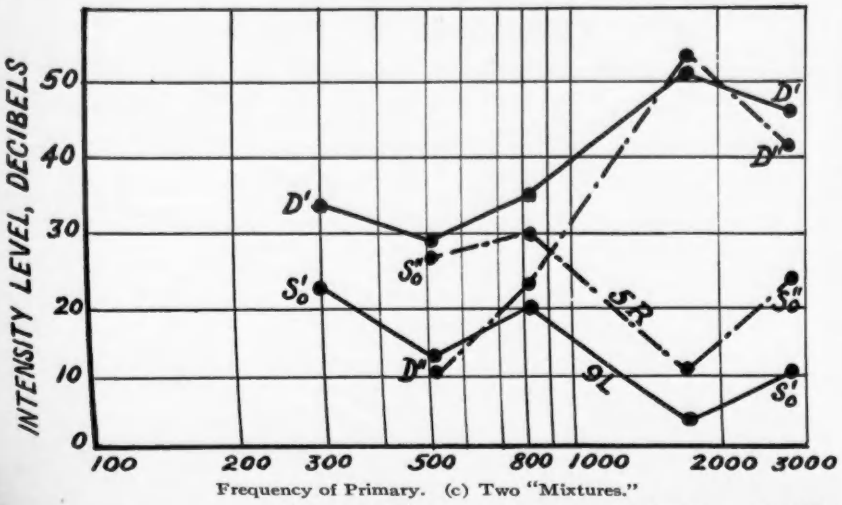
FIG. 4. Typical curves showing the relation between the differential threshold in db and frequency; also threshold and frequency.



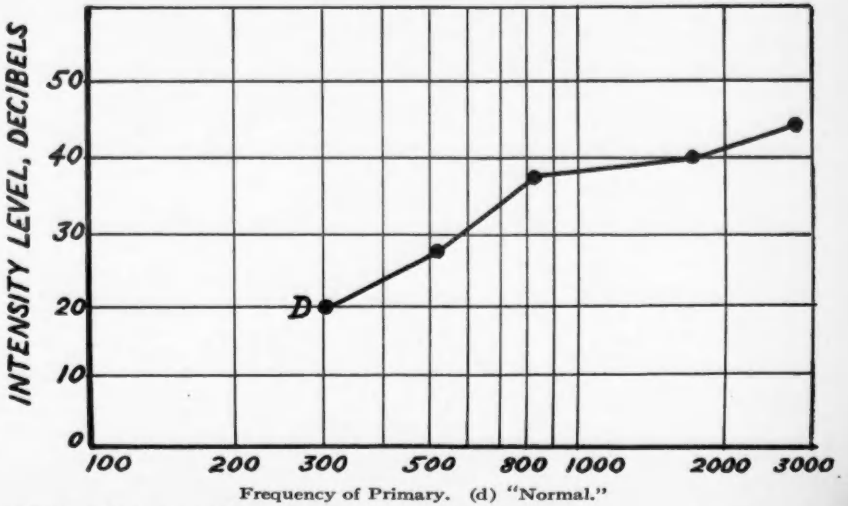
Frequency of Primary. (a) Two Perception Cases.



Frequency of Primary. (b) Two Conduction Cases.



Frequency of Primary. (c) Two "Mixtures."



Frequency of Primary. (d) "Normal."

FIG. 4. *Typical curves showing the relation between the differential threshold in db and frequency; also threshold and frequency.*

the division line, the one to the left refers to the distance from the examiner to the patient to hear "low" frequency syllables while the figure to the right has a similar interpretation for "high" frequencies.

CASES OF ABNORMALLY SMALL DIFFERENTIAL THRESHOLDS

The larger number of our cases examined had a loss of hearing in the interfering tone ranging from 10 to 30 db. When it appeared desirable to examine extremely deafened persons, an interfering tone of lessened intensity was used. In at least two cases of particular interest, where the deafness was greater than 40 db in both primary and interfering tones, the person could hear the primary tone about as well or better with an interfering tone of 20 db than without it. The result in either case depended upon the frequency of the primary used.

In another case of interest because of the unusually small differential threshold, the interfering tone was raised 30 db above threshold. The deafness was about 42 bd in both primary (2800) and interfering tones. The differential threshold for the tone of 2800 cycles/sec. was not only small or negligible but the primary tone (S_1) was a little lower (about 5 db) than that of a "normal" person when subjected to the same intensity of interfering tone (i.e., 72 db).

The above experiments with unusual cases are presented to point out that there is a limited number of deafened people who may be able to hear a tone in the presence of another loud tone at an intensity as low and possibly lower than the normal person because of the rapidity of decrease of the differential threshold with increasing deafness. Should this condition exist, our experiments indicate that it may be expected to occur more often with conduction than with nerve deafnesses (See Fig. 3). In any case, the differential threshold for certain people approaches zero quite rapidly with increasing deafness.

Taken as a whole, the above series of experiments appear to have an important bearing on the question of paracusis Willisii. The theory generally accepted to explain paracusis[3] is based on the fact that the subjects have generally a conductive impairment and are deafened in the low tones. With an interfering noise, rich in low tones, the *magnitude of the interfering energy* above their threshold is not nearly as great as for the "normal." It is, therefore, claimed that they do not hear much of the noise and are not disturbed in a conversation as much as the normal person.

[3] Shambaugh, G. E., Archives of Otolaryngology, Vol. 6, No. 3, pp. 228–236, Sept. 1928, Knudsen, V. O. and Jones, I. H., The Archives of Otolaryngology Vol. 10, No. 5, pp. 472–479.

According to our experiments, there is a lessened interfering effect of a tone with increasing deafness even when the multiple increase of energy of the interfering tone above each individual's threshold is of the same value. That this lessened interfering effect may have some bearing on the question of paracusis is further indicated by a tendency we found for the differences for conductive cases to be less than those for perceptive deafness. Any further correlations between our results and paracusis Willisii must be reserved for further experiments. The question of paracusis Willisii[4,5] under speech conditions has been receiving considerable attention recently.

An Explanation

The following hypothesis may explain the reason for a differential threshold being smaller in a deafened ear than in a normal ear. In the normal ear there must be an apparatus which masks the perception of the weaker sound in the presence of a stronger interfering one. A logical consideration would incline us to believe that this apparatus is nonexistent or is not functioning to as great a degree in the deafened ear. This apparatus possesses a very sensitive mechanism for damping, masking, or impeding the transmission of strong sounds. The function of this apparatus may be to protect the very sensitive perceptive organ of the ear.

This damping apparatus acts by reflex action. The afferent branch of this reflex arch is the cochlear nerve, which is stimulated by a loud sound entering the ear. The efferent branch is the stapedius nerve, a branch of the facial nerve. This nerve brings about a contraction of the stapedius muscle. The tensor typani muscle usually cooperates with the stapedius muscle, as both muscles contrary to the opinions of the older authorities are not antagonists, but synergists. The contraction of both of these muscles causes an increased labyrinthian pressure, impeding the vibration of the basilar membrane and thus minimizing or hindering entirely the transmission of the primary tone. The energy producing the damping must be considerably greater than that producing the perception of the primary tone.

The smaller differential threshold in deafened ears as compared with those in normal ears may be explained by the following hypothesis. Any weakening of either the afferent or efferent branch of the reflex

[4] Knudsen and Jones, Phys. Rev. 23, pp. 266-285, Feb. 1924.
[5] Hastings and Scharff, J. of Laryngology, Rhinology, and Otology, p. 261, Aug. 1928.

arch diminishes the damping effect of this mechanism and produces a better transmission of the primary tone.

In the deafened ear the afferent branch is weakened causing a diminished intra-labyrinthian pressure; therefore, a primary tone in the presence of a strong interfering tone will under certain conditions be better heard by this deafened ear, than by a normal ear. The better hearing of a tuning fork by bone conduction in a certain class of deafened ears can also be explained on the same basis.

What proof exists for the above hypothesis?

1. There exists in the eye an analogous apparatus for the protection of the retina (the sensitive perceptive apparatus of the eye). This is the constrictor pupillae muscle of the iris. The afferent stimulus, there, is not sound but light affecting the optic nerve. The efferent branch of the reflex arch is the oculomotorius nerve acting upon the sphincter pupilae, contracting the pupil and preventing the transmission of too strong light.

Nyctalopia in the eye (a condition where a person with some affection of the eye, as in central opacity on the cornea, or in nicotine poisoning can see better at night than at daytime, and can read better by placing dark gray eyeglasses in front of his eyes) is analogous to a deafened ear, which under certain conditions can hear better than a normal ear. In the eye the diminished afferent stimulus reaching the optic nerve facilitates vision by better transmission of light while in the deafened ear the diminished afferent stimulus reaching the cochlear nerve facilitates hearing by better transmission of sound.

The concensous reaction in the eye, where covering of the pupil in one eye produces a mydriasis (a widening of the pupil of the other eye) is analogous to a slightly improved hearing by one ear of a C_4 (2048) tuning fork when the other ear is obstructed by a finger.

2. The cochlear palpabral test, where the orbicularis muscle which is innervated by the facial nerve, contracts following a loud sound shows also the existence of the reflex arch between the cochlear and facial nerves.

3. Subjective noises (tinnitus) which are produced by metabolic changes or by a faulty blood circulation are better heard at night in silence. This is true since the afferent branch of the reflex arch is weakened or eliminated, thus also diminishing the damping effect of the efferent branch.

4. The weakened efferent branch in facial paralysis produces hyperacusis in some cases according to Lucae.

5. In stapesankylosis (otosclerosis), where, on account of the ankylosis of the stapes, the damping action of the stapedius muscle is eliminated, the increased hearing by bone conduction, tinitus and paracusis will be very much in evidence.

6. Dahman[6] examined in freshly prepared ear specimens, the action of the intra-auricular muscles and came to the conclusion that these muscles are not antagonists as Helmholtz and Politzer thought, but synergists serving the regulations of the intra-labyrinthian pressure.

7. Cato,[7] experimenting on cats, rabbits, etc., by laying bare the intra-auricular muscles found that these muscles contracted regularly by introducing a sound into the ear.

8. Luescher[8] observed with a specially constructed microscope the stapedius muscle in a boy, who suffered from a tear of his drum-membrane after a box on the ear. He observed that the stapedius muscle would contract when a sound was introduced into the ear and relax when the sound ceased.

9. G. Zimmerman[9] considers the middle ear not a sound conducting but a sound damping apparatus, which by the action of the intra-auricular muscles, regulates the accommodation and the intra-labyrinthian pressure.

10. C. S. Hallpike[10] states "cases in which the ordinary Schwabach is round about the normal show a marked loss in the silence room."

Remarks

The results obtained from these experiments are based upon the examinations of about 75 ears. Three factors entered into the selection of patients, i.e., intelligence, desire to co-operate and type of deafness. We repeated a few of the examinations in order to obtain an approximate estimate of the accuracy. Where repeated tests were given to a person on the same day, the factor of reproducibility of the primary tone alone averaged ± 5 db and of the primary in the presence of the interfering tone, ± 3 db. The apparatus was checked against a vacuum thermo-couple.

This series of experiments is the second of a similar nature, each series taken with different apparatus.

[6] Ztschr. f. Hals, Nasen u. Ohrenheilkunde. Bd. 24 Heft 3 Oct. 1929.
[7] Arch f. Physiologie 1912.
[8] Ztschr. f. Hals Nasen u. Ohrenheilkunde. Bd. 23 Heft 2, 1929.
[9] Arch. f. Physiologie Vol. 144, 1912.
[10] J. Laryngology and Otology Jan. 1930.

THE LOUDNESS OF AUDITORY STIMULI WHICH AFFECT STOMACH CONTRACTIONS IN HEALTHY HUMAN BEINGS*

By E. Lawrence Smith and Donald A. Laird
Colgate Psychological Laboratory, Hamilton, N. Y.

Introduction

Many of the recent experimental findings on the widespread effects of noise on health and efficiency will seem incomprehensible unless some rational explanation is forthcoming as to their cause. The experment to be reported is an attempt to discover this explanatory principle.

It is well established that emotional states affect our internal organs. The connection between noise and the emotions is not so obvious, yet everyone is familiar with the nervous start at the sound of a slamming door. John B. Watson found at the Johns Hopkins Hospital that noise is one of the only two stimuli which will bring out an overt fear reaction in babies. Some three years ago Dr. Donald A. Laird advanced the hypothesis that noise effects in adult human beings were due to less visible fear reactions.

The present experiments were aimed to verify or reject this hypothesis by measuring the amount and nature of the stomach contractions under the influence of various acoustical stimuli. The practical significance of the findings in acoustical practice can be readily seen; if a worker in a room with a stated amount of noise suffers visceral tensions akin to fear, especially in the involuntary musculature of the stomach, the room should be quieted to the point where this visceral change is avoided; or, certain tonal qualities discovered by this method to be most marked in their internal effects, could be the object of most elimination.

This field is not entirely uncharted. Dr. W. B. Cannon, working on hunger, discovered that the stomach of a cat stopped contracting when a dog entered the room. J. W. Brunswick, testing the James-Lange theory of emotions at Johns Hopkins, found that an unexpected pistol shot or the feel of a snake in a dark room profoundly affected the stomach rhythm of medical students. Dr. Tomi Wadi correlated bodily movements during sleep with the presence of hunger contractions. Within the past year Dr. Catherine Coribelle of Detroit has discovered that the volume of the spleen, liver, and kidney of dogs change in response to auditory stimuli; she has named these phenomena acoustic

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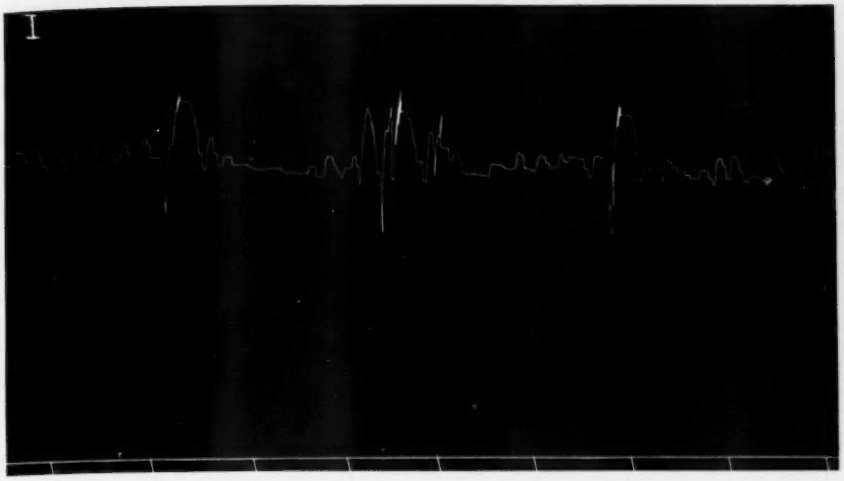


FIG. 1. *Contractions of the stomach under quiet. Subject O. H. Bottom line shows minutes.*

visceral reflexes, which is probably identical in a large part with what we have been calling the fear reaction.

APPARATUS

There are two general methods of studying the human stomach movements. One is by observing the movements under the X-ray, the other is by graphic recording of these movements from changes in air pressure in an inflated balloon in the living stomach. The balloon method was followed at Colgate. A thin rubber balloon attached to a tube is swallowed, with only slight difficulty. When in the stomach it

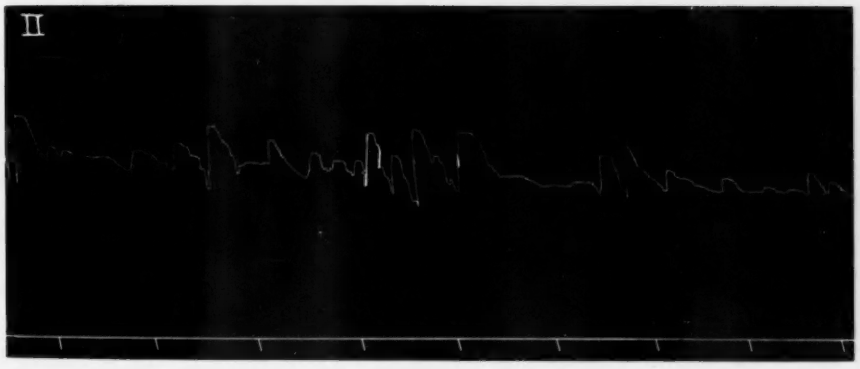


FIG. 2. *Contractions of the stomach under 80 decibels noise. Subject O. H. Note lessened rate and amplitude. The record line being nearer the time line than in I indicates a smaller stomach volume due probably to slight tonic spasm of the stomach under noise.*

is inflated to a uniform pressure of 10 cm. of water. Contractions of the balloon in the stomach force the contained air into a second balloon which is in a hermetrically sealed flask. A tube leads from this flask to a water column on which a light piston attached to a counterpoised writing point is floated. Contraction of the stomach increases the air pressure in the balloon in the flask, which in turn alters air pressure in the flask and causes the water column to rise and lift the writing point which records the movement on a revolving smoked drum.

Noises were produced by the 3A audiometer which was hooked to a specially designed amplification unit which amplifies practically without distortion. Sounds of known intensity and standard composition

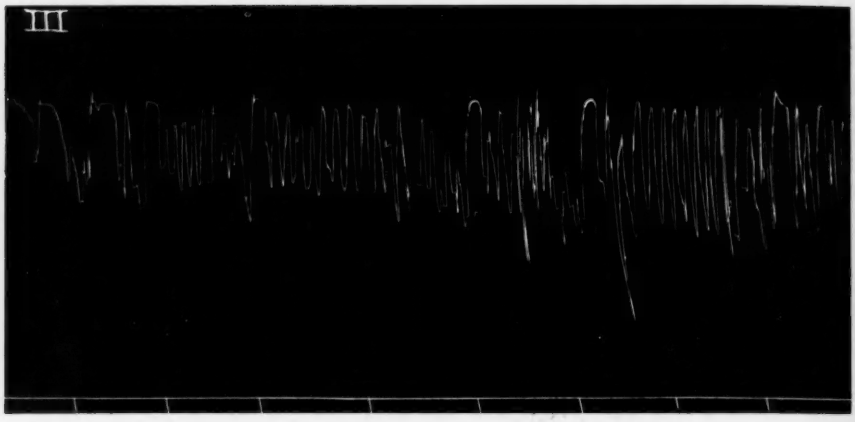


FIG. 3. *Contractions of the stomach in the after-peroid of quiet following exposure to 80 decibels noise. Note over compensatory quickening and increased contraction heights when compared with record for quiet preceding noise. Subject O. H.*

could thus be employed; these noise stimuli filled the room which was reverberant.

PROCEDURE

The subject having swallowed the balloon reclined and was given some twenty minutes to accustom himself to his surroundings. Then a twenty minute record of stomach movements was taken in relative silence as a basis for comparison, or as a norm. Then a ten minute record was obtained under 80 decibels noise in the room. This was followed by a ten minute silence period to determine the close after-effects from the noise. Then 60 decibels was used for ten minutes more, followed by another quiet period for after-effects and norms.

Results

The results, which are based on four individuals, are preliminary in nature and may be subject to some revision later. It can be safely said now, however, that the effects of the 80 decibel stimulation on stomach movements are marked. There is a decrease of 37 per cent in the number of contractions per minute caused by this noise. In addition, in

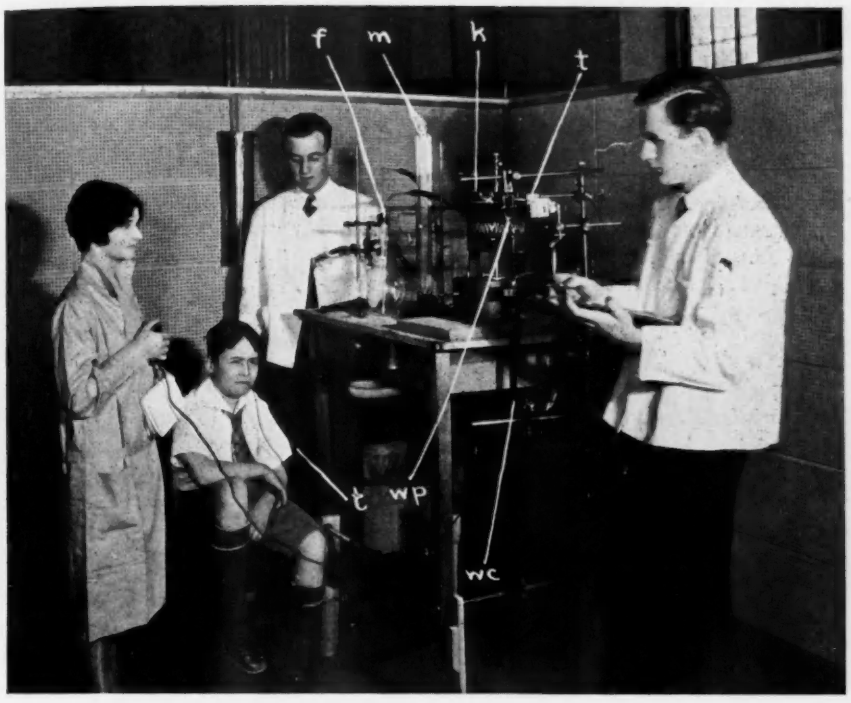


Fig. 4. *Apparatus for recording stomach contractions. t, stomach tube with balloon which is swallowed; f, intermediate balloon in sealed flask; m, manometer for standardizing pressure in the primary system within the stomach; wc, water column which responds to pressure changes within the flask; wp, counter-balanced writing point which rides on open end of water column and writes on k, the kymograph drum; t, Jacquet time marker. From left to right: Florence Hahn, technician; David Laird, subject; H. F. Brown, technician; E. L. Smith, technician.*

some subjects there is a complete change in type of contraction, and the size of the major contractions is considerably decreased. The stomach relaxes more slowly than during relative quiet. In short, there is a general lessening of stomach activity corresponding to those observed by Cannon in the cat frightened by the dog.

The after-effects in the following quiet period vary somewhat with the individual; some subjects show an overcompensatory quickening

of rythm, accompanied by more vigorous contractions. Others simply return slowly to normal.

Sounds of 60 decibels do not have as marked an effect on stomach movements. There are, however, about 10 per cent fewer contractions per minute, and a slightly altered type of contraction wave. The after-effects were similar to those observed under the 80 decibel stimulation, but in a lesser degree.

In conclusion it may be said that the experiment indicates a rather profound effect on involuntary muscular activities of the stomach with noises of 60 decibels or above. These effects are at least similar to those produced by what is generally called fear, if, indeed, they are not essentially a fear reaction.

Acknowledgments: E. L. Smith, R. J. Kehoe, O. Hubbell, and H. F. Brown served as experimental subjects. The special amplifier was designed by Horatio Lampson of the General Radio Co. Byron J. West, M.D., gave medical attention. H. F. Brown and R. J. Kehoe also helped construct and operate the apparatus.

THE EFFECT OF NOISE INTENSITY AND PATTERN ON LOCATING SOUNDS*

By Walter G. King and Donald A. Laird
Colgate Psychological Laboratory, Hamilton, N. Y.

Introduction

Measurements of the localization of the direction from which sounds come have previously been largely only of academic interest, and have been directed principally to theories of local signs or the functioning of the hearing apparatus.

The present experiments, however, have been concerned with the more practical question of how one's accuracy in detecting the direction from which a sound comes to his ears is affected by the noise present at that time in the hearer's surroundings. There are practical applications of this general problem in the development of "third dimensional" telephony, and more especially in telling which one of a dozen telephones rang in a general office with a telephone on each desk, —this is not a matter of getting the wrong number, but rather the reverse of answering the wrong telephone.

Apparatus

It had been thought that standard sound cages and localization methods could be used for this work, but six months preliminary experimentation showed that these more established methods would have to be discarded due principally to two factors: 1. Telegraphing of sound along the rigid framework of the sound cage. 2. Reflection of the sound by the framework. Conventional sound cages had to be dispensed with, except for the head clamp which held the head of the person being tested in a constant position. A moveable protractor scale of sound absorbing material was adjusted to be on a level with the subject's ears, one meter from the center of his head, on a horizontal plane, and with the zero mark on a line with the median plane of his head.

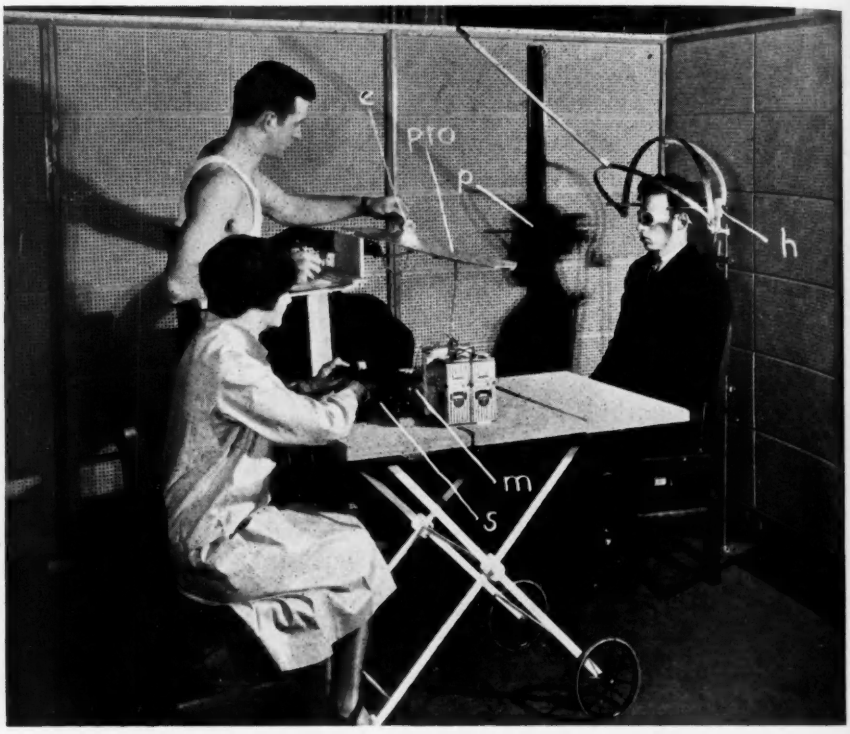
The noise to be located was made by a small watch case electric clicker which is supplied with the Marietta sound cage. This clicker was held between the fingers of an operator above the degree marks on the protractor with the thin edge vertical. The rhythm of clicks was

* Presented by permission of The Celotex Co. Copyright 1930 by Dr. Donald A. Laird.

regulated by an electric pendulum and a second operator so that a pair of clicks separated by 0.3 seconds was produced.

PROCEDURE

The operator holding the clicker above zero on the protractor, and watching the swing of the pendulum, would command the blind-folded



Apparatus set-up in localization measurements. Head clamp, h, holds the head of E. W. Tanner, subject. The clicker, c, is held vertically along the protractor scale, pro, by W. G. King, technician. The timing of the clicks is controlled by the pendulum, p, and the silent mercury switch, s, which is operated by Florence Hahn, second operator. The electrical supply to the clicker is checked through the meter, m. Mr. King's shirt is removed since preliminary experimentation revealed that the rustle of clothing served as secondary clews. This photograph was not taken in the test room, which was too small to accommodate the camera.

subject being tested, "Ready! *Listen*!!" One second later a pair of clicks occurred at zero, and a second following this another pair of clicks was sounded, either at zero or at a changed position to the right or left. The one being tested reported whether, in his sensory judgment, the direction of the second pair of clicks was the same or different than the

first pair. The degrees through which the clicker moved for the second pair of stimuli was varied until the amount of directional change was found which brought forth 80% correct judgments from the person being tested. There is considerable improvement due to practice, and results are presented only after very definite practice levels had been reached.

Results

1. *Detection of direction in "silence."* The tests were performed in the relatively sound proof room of the Colgate laboratory. This room is ten feet in each dimension. During the so-called period of silence the ceiling and side walls were covered with panels of commercial sound absorbing material with an accepted absorption coefficient of 0.70. The floor was covered with a felt rug. The smallest change in direction of sound which could be detected by the six subjects tested with the demands of 80% accuracy was 1.8°, averaged, with a range from 1.5° to 2.0°.

2. *Detection of direction with 45 decibels noise in an absorbent room.* The same test room was used, with absorbing panels and rug intact. The buzzer noise of the 3A audiometer was amplified, however, to 45 decibels in the subject's position in the center of the room through a special amplifier with the dynamic speaker one meter directly to the right of the subject's right ear. This reproduced to some extent the entrance of noise from an open window or from a door connecting to an adjoining and noisy room. The sound of the clicks was about 30 decibels above the amplified audiometer sound.

The smallest change in direction of sound which could be detected by the same subjects with the noise in the room was 4° for 80% right judgments, ranging from 3° to 5°. In an absorbent room it would appear, therefore, that the threshold of discriminating direction of this sound is more than twice as great when 45 decibels noise is present as when relative silence prevails.

3. *Detection of direction in a quiet but reverberant room.* The same test room was used for this phase of the experiments, but the felt rug and the commercial sound absorbing material were removed from the walls and ceiling. The room thus became reverberant with painted plaster walls and oiled hardwood floor. The smallest average change in direction of the pairs of clicks which could be detected with 80% accuracy under this condition was 3.4°.

It would appear that a reverberant but quiet room of this size is

nearly as troublesome in locating the direction of sound as is a highly absorbent room with 45 decibels of noise present. If larger rooms had been used it is possible that the difference would have been even more striking, due to the acoustical changes incidental to increased size. But even a small room such as was used has pattern effects when reverberant which makes these perceptions more inaccurate.

4. *Detection of direction with 45 decibels noise in a reverberant room.* The room was the same as in section 3, above. It is not possible to give averages for this phase, for some very significant reasons. Following their usual habits of discrimination in the experiment, the trained subjects would not be able to reach a threshold of 5 to 10 degrees in the first twenty trials. Then they would brace themselves, tense muscles, and concentrate their maximum upon each "Ready! *Listen*!!" and have a threshold of as low as 2° for perhaps twenty trials, following which their threshold would again become abnormally high, probably due to fatigue.

So, although it is impossible to give a satisfactory scientific average for the threshold in a reverberant room we can but infer as follows: An individual's detection of the direction of sound in a relatively noisy and reverberant room varies from moment to moment, but approximates his threshold in an absorbent room of the same noisiness only when extreme concentration is exerted, and cannot be maintained for long. Through extreme concentration he may occasionally be more accurate in the reverberant and noisy room, but throughout even a short period of time he will be erratic rather than accurate.

Acknowledgments: E. Lawrence Smith, E. W. Tanner, W. W. Wille, Jr., G. F. Smith, E. C. Miller, and F. K. Berrien served as observers. R. F. Stanley was second operator. The amplifier for the 3A audiometer was designed by Horatio Lamson of the General Radio Co.

ACOUSTICS OF LINCOLN HALL, THEATER AT THE UNIVERSITY OF ILLINOIS

By F. R. Watson
University of Illinois

Recent theory indicates that perfect acoustics in an auditorium may be obtained by observing two requirements,[1] first, the conditions favoring the perfect generation of sound, and second, those insuring perfect listening.

For the generation of sound, the reflecting walls near the speaker or musician play an important part. If they are not too far distant, the reflected sound beneficially reenforces the sound being generated, without distortion, and has the further advantage that the performer can "hear himself," thus allowing him to modify his efforts until they sound satisfactory. Petzold's work[2] indicates that these reflecting walls should not be further distant than about 25 feet from the source to avoid distortion.

After the performer has had opportunity for the perfect generation of sound, the second requirement comes into consideration; namely, the adjustment of conditions for perfect listening. This is brought about by reducing or eliminating any reflected sounds except those already mentioned. The auditor would thus get only the direct sound, together with the few reflections from the surfaces near the performer. It is commonly supposed that reflected sound is needed to give sufficient loudness in a room, but it is easy to show that the increase in loudness over the direct sound is small.[3] Also, it has been found that speaking is better understood in deadened rooms than in those that are reverberant.[4]

The outdoor theatre appears to fulfill the requirements for perfect acoustics. It has practically no reflecting surfaces about the audience, thus insuring satisfactory listening; and if it is designed with suitable reflecting walls at the stage, it will fulfill also the conditions for perfect generation of sound. But it has the disadvantage that auditors are disturbed by extraneous outdoor sounds of airplanes, automobiles and other agencies. Among indoor auditoriums that support this theory there are certain types of rooms used for recording sound for talking

[1] Science, 67: 335–338 (1928).
[2] Elementare Raum Akustik.
[3] Watson, F. R. Ideal Auditorium Acoustics. J. Amer. Inst. Archt. 16: 259–267 (1928).
[4] Knudsen, The Architect and Engineer, Sept. 1926.

motion pictures. The orchestra is placed in one end of the room, near reverberant walls, while the recording microphone is placed some distance away at the other end of the room, which is deadened to reduce reflection. These rooms produce more satisfactory films than ordinary rooms.[5]

An opportunity to test these ideal acoustic conditions in an auditorium was afforded in the construction of the Lincoln Hall Theater at the University of Illinois, due to the cooperation of the Supervising Architect, Professor James M. White

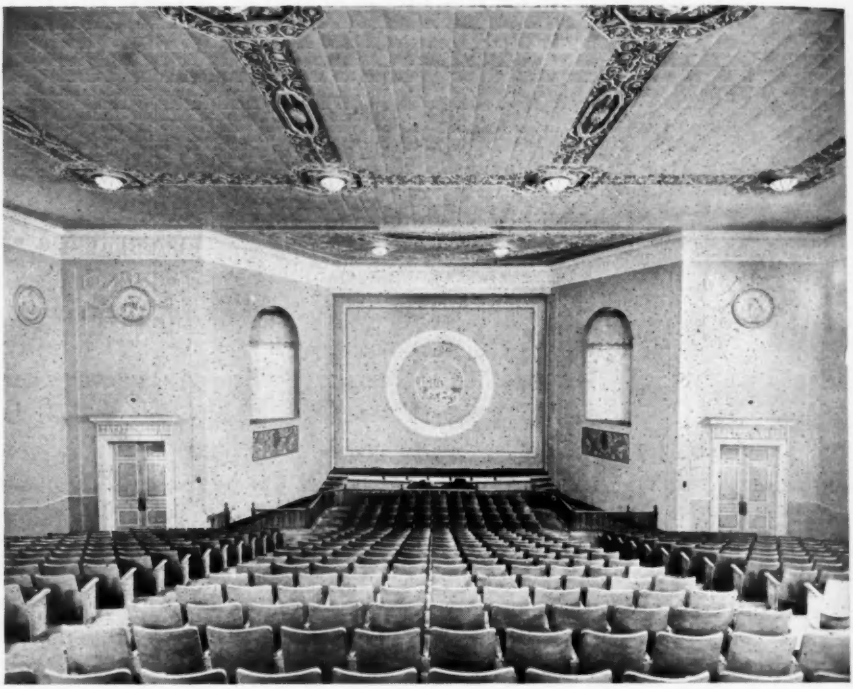


FIG. 1.

Lincoln Hall Theater, University of Illinois, which has Excellent Acoustics.

The theater is not large, having a capacity of about 800 audience, and is intended primarily for lectures; but a stage house allows opportunity for theatricals. The room is rectangular in shape. When used for lectures, the stage is shut off, with the lecturer on a platform in

[5] Maxfield, J. P. Acoustic Control of Recording for Talking Motion Pictures. J. Soc. Motion Pict. Eng. 14: 85–95 (1930).

front of the stage curtain. Plane walls, placed diagonally at either side of the lecturer, reflect sound to the audience and allow the speaker to hear himself. The absorption is furnished by leather upholstered seats and an effective material on the ceiling. The optimum time of reverberation (1.57 seconds for the volume of 138,000 cu. ft.) is obtained with 394 auditors present,—a little less than half capacity. The stage house is deadened by a number of heavy velour curtains that are intended also for decorative and lighting effects. A huge plastered cyclorama at rear of the stage, intended primarily for lighting effects, acts as a reflector of sound, by which the actors may hear themselves.

The acoustics are regarded as satisfactory. Auditors can understand easily in all parts of the auditorium. Actors like the conditions for plays, and speakers find it easy to lecture. The theater gives opportunity for further experiments, and it is expected that the results will be instructive in the design of future auditoriums.

ARE ACOUSTICAL MATERIALS A MENACE IN THE HOSPITAL?

By Charles F. Neergaard
New York City

That a hospital should be free from noise is axiomatic. The comfort, even the life of the patient demands quiet. Yet our modern fireproof construction, if deliberately designed to accentuate noise, could not do so more successfully. The steel and concrete frame transmits the waves of sound throughout the building. The hard finished walls and ceilings reflect and magnify noise to perfection. Patients rooms are bare of absorbing materials,—with no rugs, stuffed furniture nor heavy hangings, so that the quiet which these provide in a home or hotel bedroom must be artificially attained.

Further complicating the hospital's problem are its exacting requirements for cleanliness. Many of the walls and ceilings, where acoustical treatment would naturally be used, are washed from four to six times a year. This renders it impractical, from the standpoint of upkeep, to apply materials which are finished with cemented membranes or water color acoustical paints. Experiments have shown that the cement soon looses its grip and the repainting which necessarily follows each washing makes maintenance excessive.

In addition to the problem of upkeep there has been a general feeling among hospital administratore, doctors and architects that the various substances used in acoustical treatments, porous plasters, soft organic felts, fibres, etc., presented a potential menace as abiding and breeding places for germs and bacteria.

During the past three years a group consisting of hospital consultants, architects, engineers, builders, and manufacturers have cooperated in a series of tests with a view of determining how the hospital's difficult requirements for sound absorption and sound insulation could be met most practically and economically. The paper presented today is the third in a series on "How to Make the Hospital Quiet"; the first, which covered an analysis of the cost, maintenance, efficiency and permanence of various acoustical materials, was published in the March, 1929, MODERN HOSPITAL. The second, published in the April number, indicated where acoustical treatment and sound insulation should be used; touched on related phases,—flooring, ventilation in noisy rooms which permits the windows to be kept closed, and other

pertinent subjects. From a series of calculations based on an institution under plan it was found that a 100 bed hospital could be made reasonably quiet at a cost of a trifle over 2¢ per cubic foot. This represented an increase in the construction budget of 2½%, the entire cost for acoustical treatment, sound insulation and special structural features being approximately $10,000 or $100 a bed.

None of the materials available at the time these studies were made seemed entirely satisfactory for hospital use and we ventured to set up an ideal specification,—namely an inorganic, highly porous tile, smooth finished, even glazed perhaps, and tinted, never needing to be painted and everlastingly washable. It should have more absorption than the present plasters, a coefficient of at least 50%. Surely, we thought, this is an achievement not impossible for our miracle working industrial chemists and resourceful engineers. We further set a price limit of 50¢ a square foot, installed. With hospital construction averaging over $200,000,000 annually there seemed indicated a market large enough to warrant research.

This third paper outlines an effort to determine whether acoustical materials are really a menace. A material, to possess any value for sound absorption, must of necessity be porous. Hospital people have been apprehensive lest such substances would permit the penetration of bacteria and that such bacteria would remain viable longer in or upon the acoustical materials than on the usual smooth surfaces of the room. An investigation was conducted in the bacteriological laboratories of Yale University on Acoustical materials commonly used in hospitals, to ascertain:

1. To what extent bacteria penetrate into the substance under test when applied
   a. by direct application (as with a brush)
   b. By droplet deposition (as with a spray).
2. To what extent bacteria so applied remain viable upon the surfaces and within the texture of the materials.

The following acoustical treatments were studied, the letters (on the left) being arbitrary designations:

A. Nashkote, Type A-1-S-Acoustical hair felt with a cemented muslin membrane, unpainted.
B. Acousti-Celotex-Compressed Sugar Cane Fibre, drilled with 400 1/4″ holes per sq. ft.
C. Nashkote, Type AX-Acoustical felt with muslin cemented on and water color painted.

D. Nashkote, Type B-332-Acoustical hair felt with perforated glazed oilcloth cemented on.

E. Sabinite—Porous acoustical gypsum plaster.

It was originally intended to make the studies with a microorganism of known pathogenic properities, as the streptococcus, to simulate in some degree the average conditions which might be encountered. This was dismissed, however, because of the difficulty both of cultivation and of identification of this organism in the presence of the non-pathogenic bacteria which were found to be present, and it was considered unwise to subject the samples under test to any sterilizing procedure such as might alter their state. The non-pathogenic B. prodigiosus was finally selected for the study because of its relative ease of cultivation and identification, and because there was no indication of its presence in the materials.

It was necessary as a preliminary experiment to determine whether the materials under test exerted any bacteriostatic or germicidal action. Tests made using sterilized samples of each of the five materials with the streptococcus, pneumococcus, diphtheria bacillus, typhoid bacillus and B. prodigiosus, and unsterilized samples with B. prodigiosus, indicated that under conditions of the test the materials exerted no appreciable bactericidal action, and demonstrated that the B. prodigiosus could be satisfactorily used for the experiments.

A culture of B. prodigiosus was grown on an agar medium and the suspension, obtained by washing off the growth with physiological saline, was applied in a thin film by means of a camels hair brush upon the surface of the materials. The test sections were cut into four equal layers, parallel to the outer surface to determine the penetrability of the material by the bacteria. No. 1 was the surface layer to which the solution was applied, No. 2 the next layer, No. 3 the third, and No. 4 the layer limited by the innersurface of the sample. Each of the four portions of the five samples was transferred to a tube of nutrient bouillon, thoroughly shaken, placed in an incubator for 24 hours, plated to plain agar, and further incubated. The plates were then examined for colonies of B. prodigiosus, the results being recorded merely as positive (plus) if colonies were present, or negative (minus) if absent, with no particular attempt being made to obtain precise quantitative values. The times of testing are expressed in days after the culture was applied.

Material	Layer	1 Day	2 Days	4 Days	6 Days	8 Days	12 Days
A—(Nashkote, type A-1-S)	1	+	+	+	+	+	−
	2	+	+	+	+	+	−
	3	+	+	−	−	−	−
	4	+	+	−	−	−	−
B—(Acousti-Celotex)	1	+	+	+	+	+	−
	2	+	+	+	+	−	−
	3	−	−	−	−	−	−
	4	−	−	−	−	−	−
C—(Nashkote, type AX)	1	+	+	+	+	−	−
	2	+	+	+	−	−	−
	3	+	+	−	−	−	−
	4	−	+	−	−	−	−
D—(Nashkote, type B-332)	1	+	+	+	+	+	−
	2	+	−	+	+	+	−
	3	+	+	+	−	−	−
	4	+	−	−	−	−	−
E—(Sabinite)	1	+	+	+	+	+	−
	2	+	+	+	−	−	−
	3	+	−	+	−	−	−
	4	+	−	−	−	−	−

To summarize the table, results were negative in the 3d and 4th layers after 1 or 2 days, but positive on the 1st and 2d layers up to 8 days, all tests being negative on all materials at the expiration of 12 days. There was little variation in the different materials.

It should not be attempted to read these results too closely. The materials were difficult to subject to bacteriological examination; it is possible that contaminating organisms may have obscured the results in some instances, and other samples might have given results of another character. It would appear, however, that when applied by brushing the culture is absorbed, the degree of absorption being roughly the same for all of the materials, and the bacteria absorbed into the deeper layers die off more quickly than those on the surface, although this may be due to the smaller numbers present.

In addition to the above test of applying the culture by brushing, the bacterial suspension was evenly distributed over the samples by spraying with an atomizer for 30 seconds, since it was felt that this procedure more closely simulated room contamination under natural conditions. Tests were made in the same manner and at the same inter-

vals as before, and it was found that the results were in general agreement with those of the previous experiment.

The tests dealt only with the question of bacterial viability and but one organism, a non-pathogene, was used so the data do not directly answer how long pathogenic bacteria would live. For an interpretation, however, it must in fairness be stated that the tests were undoubtedly made under extremely severe conditions and it may well be questioned whether under natural conditions bacteria which might become deposited upon the surface could penetrate into the deeper layers.

While no attempt was made to obtain accurate data of a quantitative nature, bearing upon a possible multiplication of the bacteria within the substance of the samples under test, the platings made of the successive cultures clearly indicate a *progressive diminution* in the bacterial numbers. Certainly there is no evidence of *bacterial proliferation*, even with the saprophytic *B. prodigiosus* and there is every reason to believe that the materials composing the samples would provide an even less satisfactory source of food supply to organisms accustomed to a more highly developed *parasitic* existence.

Since acoustical materials are usually placed upon the ceiling, it is also unlikely that bacteria would be deposited in a moist suspension. A possible exception to this statement may be made in the particular instance of bed patients having respiratory tract infections who cough, thus directing a spray of droplets toward the ceiling, although it is a matter of conjecture if and how many such droplets may reach the ceiling.

It is sometimes felt that the porosity of acoustical materials makes such materials ideal for harboring bacteria, but when considering the relative size of the openings in an acoustical material and in the ordinary plaster wall, in comparison to the microscopic size of bacteria, it is seen that the seemingly smooth surface is also relatively porous. It is a matter of routine in hospitals to wash the floors and walls, and washing the less easily contaminated acoustical ceiling in the same manner should produce the same cleaning effect. It is important, therefore, to use in hospitals only such acoustical treatments as give promise of withstanding frequent washing and repainting, without loss to their absorbent qualities.

The old notion is no longer held that bacteria have wings and can fly about the room. Contamination is usually due to actual contact. It is possible of course for floating dust particles to carry bacteria, and even probable that contamination may so occur. Such contamina-

tion, however, can also occur with the standard plaster ceiling as well as an acoustical ceiling, so this is not a unique property of the latter. Granting that in theory bacteria may enter the pores of the acoustical material, just as they do those of the plaster wall, it is extremely doubtful if they maintain their viability longer in the one than in the other, and there is no reason to suppose that they would become mechanically dislodged from the one more readily than from the other. It has been found that dust does not seem to enter porosities of acoustical materials because of the fact the air spaces contain dead, not moving, air. The dust collecting upon the surface can usually be removed by brushing, vacuum cleaning or washing. Theoretically, a porous surface of any type is a potential danger; actually the danger is in fact problematic.

The modern attitude regarding the possibility of contamination and the proper procedure for avoiding it is well expressed in Bulletin No. 60 of the American Hospital Association upon cleaning rooms or wards. "Contagious disease is nowadays best handled when doctors, nurses and others in attendance look upon the care of contagion as a question of technique, pure and simple. Practically the same technique applied in the isolation ward as is used in the modern operating room, reduces cross-infections to a minimum. In other words, the nurse considers as infected only the patient and articles which have touched his body or have touched something else which previously touched his body."

A statement by a member of the American College of Surgeons, who is an accepted authority on hospital problems, may be of interest. "Placing the material on the ceiling where it is out of the reach of patients and workers, and providing it with an enameled surface which can be washed, is undoubtedly a safe practice. The adequate fumigation of the room at the necessary intervals will take care of properly disinfecting the sound absorbing material along with the other articles and wall surfaces in the room."

Acoustical materials of the types tested have been used successfully in a large number of hospitals. Acoustical engineers are alive to the exacting requirements of hospital technique and even in the brief interval since these tests were made, several new and better methods of acoustical treatment have been devised.

AREA AND PATTERN EFFECTS IN THE MEASUREMENT OF SOUND ABSORPTION

By John S. Parkinson
Johns-Manville Corporation

It has been recognized for sometime that the area and arrangement of absorbent material used in tests had a bearing on the coefficient of absorption obtained. Standard practice has been to use areas of material sufficiently large so that it might be safely assumed that the coefficients obtained would be accurate. It will be obvious, however, that in treating actual rooms with acoustical treatment, occasions arise where the arrangement and spacing of the material may have a decided effect on the absorption coefficient obtained. For this reason it seemed desirable to make a thorough study of the causes underlying these phenomena, and if possible to work out formulae by which to predict results in the future. The following discussion gives a summary of the results obtained.

Other investigators, notably Dr. P. E. Sabine and Prof. F. R. Watson, have observed these phenomena and have commented upon them. Summarizing their conclusions, it appears that the absorption coefficient is inversely proportional to the area of the sample, the proportionality factor depending upon the frequency, and that long narrow samples are more absorptive than square samples of the same net area.

Certain experiments conducted several years ago by the writer in the sound chamber of the Burgess Laboratories yielded similar results. It was possible to show that the absorption was inversely proportional to the area under test, that the shape of the test sample had a bearing on the problem, and further that the changes in absorption were not in any way proportional to the area of edge exposed.

Chart 1 gives a set of typical values obtained on 1″ Asbestos Akoustikos Felt tested in different patterns and different spacings. (These measurements and those following were all obtained at the Riverbank Laboratories, and grateful acknowledgement is made to Dr. P. E. Sabine for his assistance.)

In all cases the total area of felt tested was 48 sq.ft. The absorption coefficient of this felt tested in the standard fashion in a solid rectangle 6′ × 8′ is as follows:—

Frequency	128	256	512	1024	2048	4096
Absorption	.11	.31	.59	.68	.58	.46

TYPICAL ABSORPTION COEFFICIENTS RESULTING FROM VARIOUS SPACINGS
(All Values For 1″ Felt)

Area of Unit	Width of Spacing	Frequency 128	256	512	1024	2048	4096
2′ x 2′	2′	.07	.30	.78	.96	.78	.48
2′ x 2′	4′	.11	.32	.93	1.17	.86	.62
1′ x 8′	1′	.10	.30	.73	.82	.76	.71
1′ x 8′	2′	.11	.30	.78	.94	.79	.70
1′ x 8′	3′	.11	.32	.85	1.15	.84	.66
2′ x 8′	1′	.09	.30	.74	.79	.68	.60
2′ x 8′	2′	.09	.31	.76	.84	.71	.65
2′ x 8′	4′	.11	.31	.79	1.05	.74	.60

The reason for using 1″ felt in these experiments was that this material offered a flexible and easily manipulated medium, and one which was not likely to change its characteristics greatly on handling. For the sake of accuracy the material was tested after the conclusion of the tests, and where necessary corrections were made.

While the practical results of these phenomena were more or less evident, the actual causes were not so apparent. In the preliminary work the following possible causes were suggested. First, additional surface is exposed at the edges. Second, the sample is surrounded by reflecting instead of absorbent surfaces. Third, by changing the weight and the edge damping, the diaphragmatic response would be altered. Fourth, diffraction effects become possible. The theory indicated that sound energy flows in toward an isolated sample from all around it. In other words, more energy strikes the sample than would normally reach it if the sample affected its own area of wave front and no more. That this is true is attested by the fact that in some cases it has been possible to obtain apparent absorptions of more than 100%. This attraction of energy may happen in at least two ways. First, in the pores of the sample and in the immediate neighborhood of its surface it is reasonable to suppose that friction and interference have robbed the molecules of their directional vibration and have substituted the random vibration of heat. In consequence, the directional vibration which exists in the surrounding elements of air would have a tendency to flow into this area or random vibration. Second, as has been pointed out, the sample is surrounded by highly reflecting surfaces where before the surfaces were as absorbent as itself. We might assume, then, that a part of the sound energy which reaches the sample is reflected at an acute angle from the surrounding wall and loses energy in passing over the absor-

bent material. It will be obvious that this could not have happened if the adjacent surface had been highly absorbent. Such reasoning leads one to the conclusion that for all materials where the coefficient is less than unity some diffraction takes place from one element of surface to the next, the magnitude of this effect varying with the absorbing efficiency of the material. It is possible, therefore, that the sound absorption coefficients which are ordinarily given for materials are greater than would obtain if the sample were suspended in mid-air in front of a train of sound waves moving at right angles to it. However, this is not a practical case, and it has not been possible to obtain much experimental evidence.

Certain experiments were conducted to determine the magnitude of the so-called edge effects. The results on 1″ and 2″ Acoustical Felt are as follows:—

	128	256	512	1024	2048	4096	
1″ Felt	.08	.29	.74	1.07	.84	.70	edges uncovered
1″ Felt	.07	.30	.78	.96	.78	.48	edges covered with wood strips
2″ Felt	.16	.63	1.10	1.22	.92	.88	edges uncovered
2″ Felt	.19	.74	1.07	1.10	.79	.86	edges covered with wood strips

(All Samples Tested in Squares 2 × 2 spaced 2′)

These results are somewhat contradictory, but the fact is apparent that the difference produced by covering the edges is not nearly enough to account for the increase in absorption produced by spacing. The same result is obtained by a calculation of the relative area of edge exposed. For example, with 2′ × 2′ squares of 1″ felt the edge area is equal to $\frac{2}{3}$ of a square foot. This would indicate an increase of 16.6% if the absorption were strictly proportional to the area, whereas the actual increase provided by the spacing varies from 25% to 60%, depending on frequency.

It is possible that the wood strips did not completely prevent access to the edges of the samples. However, an experiment by the writer during some previous work indicated that when the edges were covered completely with a plastic material such as Plaster of Paris there was no decided difference between the results thus obtained and those obtained using wood strips.

The second possible theory to account for the results obtained in these tests was that there was a change in the vibratory response of the

samples. This is unquestionably true, since a change in area and hence in weight always produces a change in the natural mode of vibration of a diaphragm. However, it seems reasonable to suppose that any marked effect resulting from such a change would make itself apparent at the low frequencies. An examination of the results will show that there was practically no change in frequencies below 512. Also, as will be shown later, a given ratio of treated to total area will produce essentially the same results regardless of the shape or size of the individual samples, a condition which would not hold if there were any marked variation due to the type of structural vibration.

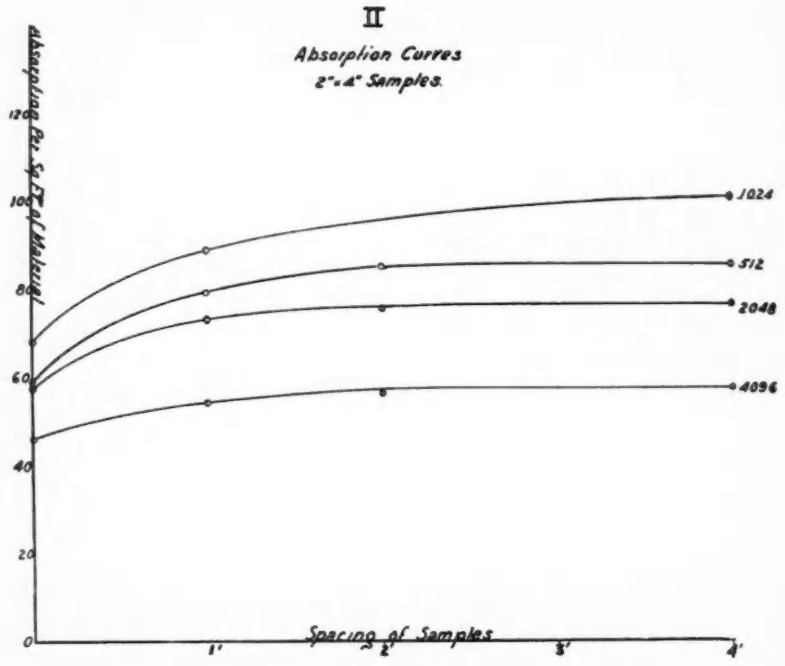
This brings us to the subject of diffraction, which is presumably the underlying phenomenon in all this work. It is possible that, as mentioned, a part of the effect may be due to reflection at an acute angle from surfaces adjacent. However, this is in a sense a part of the same phenomenon and difficult to differentiate. In the original program an experiment was designed to investigate this effect but a lack of time prevented its being performed. The experiment was to consist of testing the samples raised on boxes or beams so that any sound striking the intervening areas would proceed onward instead of being reflected. There would inevitably have been reflection from the floor, but any such reflection would have been at right angles for the most part.

There are a number of things among these experiments which confirm the theory of diffraction. In the first place, an increasing spacing always produced an increased absorption. This was to be expected if the sound energy was being drawn in from around the sample. Likewise the relation between spacing and absorption nearly always proved to be an exponential relation, which was to be expected from the theory.

Chart #2 shows a typical set of curves for a felt tested in rectangles 2′×4′. The ordinate is the absorption per sq.ft. of felt, and the abscissa gives the number of feet of spacing between the rectangles. It will be noted that each curve approaches a maximum value beyond which further increase in spacing does not appear to be effective. The point at which this maximum is reached depends on frequency. In general the maximum effective spacing is greater for low frequencies than for high, although in none of this work was a spacing width of more than 5′ effective. This maximum effective spacing appears to depend somewhat on the initial absorption of the material as well as on the wave length. There were cases where the curve reached its maximum at 512 cycles sooner than at 1024, which is to be attributed to the fact that the initial absorption at 1024 was 68% as against 59% at 512. It seems possible

that, given equal wave lengths or even wave lengths which are of the same general magnitude, a more efficient absorber will make itself felt over a larger area.

Another interesting phenomenon may be observed. This is the fact that when the ratio of wave length to spacing remains constant, the longer waves appear to have a wider spatial influence. To be more specific, if we examine the curves for 2′×8′ samples, we observe that a 2′ spacing produces a greater increase in absorption for a 2′ wave than a 1′ spacing for a 1′ wave, which in turn is more effective than 6″

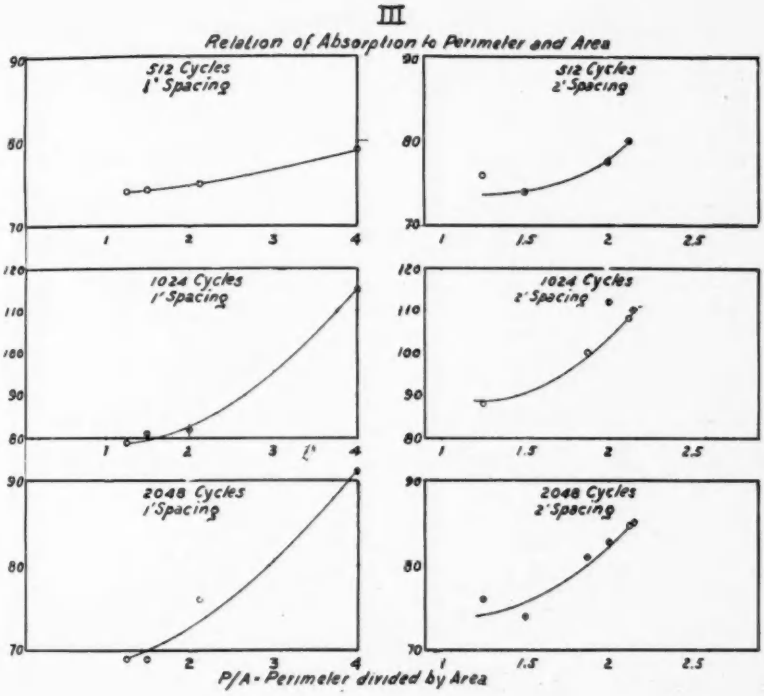


spacing on a 6″ wave, etc. This may be interpreted to mean that the law of diffraction, which holds that the amount of change in the direction of the wave is proportional to the length of said wave, is only approximately true and more exact for small wave lengths than for greater ones. This of course would appear to be a natural conclusion, and the experimental results bear it out in a strikingly consistent manner.

One important discrepancy in all this reasoning will be at once apparent. The two lowest frequencies—128 and 256 cycles—show no change in absorption whatever due to spacing except in the case of 2″ materials. An attempt will be made to explain this later as being due to the nature

of the absorption, but as far as the general theory of diffraction was concerned these results were quite unexpected.

The relation which developed between the area and shape of the test samples and the increase in absorption provided still further confirmation of the diffraction theory. It is perhaps unfortunate that the experiments did not include tests on a single sample to be varied in area and in shape. A future investigation should surely include this. However, it is possible to show a more or less consistent relation between the absorption and the dimensions of the test samples when the spacing of

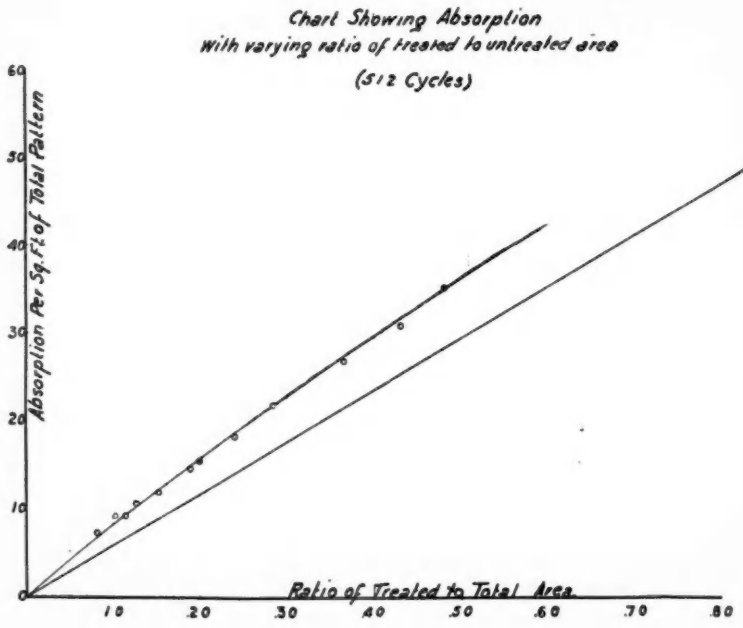

III
Relation of Absorption to Perimeter and Area
512 Cycles 1' Spacing
512 Cycles 2' Spacing
1024 Cycles 1' Spacing
1024 Cycles 2' Spacing
2048 Cycles 1' Spacing
2048 Cycles 2' Spacing
P/A - Perimeter divided by Area

the pattern is kept constant. The absorption per sq.ft. of any given sample increases as the quantity p/A increases, p being the perimeter and A the area. This increase is not always in direct proportion but appears to be related to the wave length. This relationship indicates, among other things, that a long narrow sample is more efficient than a square sample of the same area, and that the absorption coefficient per sq.ft. becomes steadily greater as the area of the test sample becomes smaller. Both these facts had been indicated by previous research, and both are natural corollaries of the diffraction theory. Chart #3 shows a

general plot of this relation. Most of the variations in the points are probably to be attributed to the fact that in so many cases the wave length was of the same order of magnitude as the dimensions of the sample.

The first and most obvious result of this work from a practical standpoint is that by spacing small areas of treatment at a little distance from one another more absorption may be obtained from a given area of material. This means a saving in material, and if the arrangement is such that the additional labor is not too great, a saving in net cost.

IV

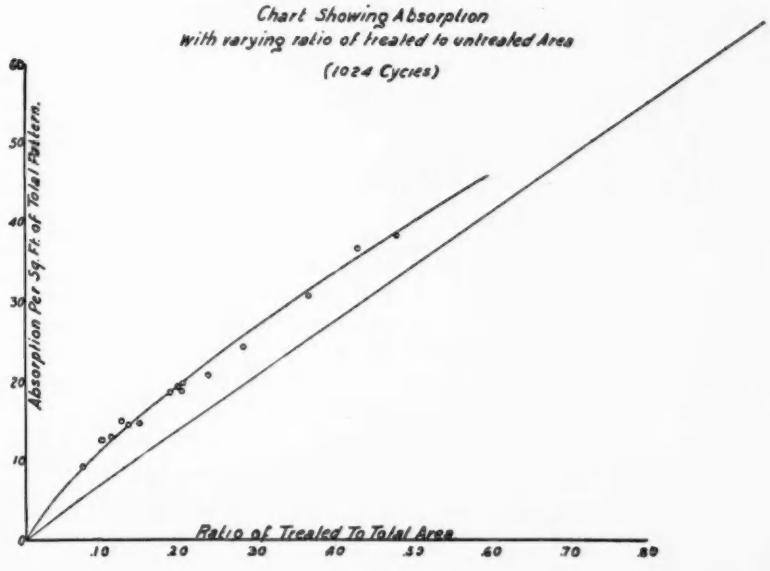


At this point it seems desirable to emphasize that the absorption has been computed in two different ways during the course of this discussion In the tables and charts given above the absorption has been given in terms of the absorbing power per sq.ft. of felt. In other words, measurements were made to determine the total increase in absorption of the chamber after the material had been brought in and correctly laid out. This increase in absorption was divided by the area of felt, thus giving a working coefficient per sq.ft. of felt. In some of the following work,

however, it has been more useful to divide this increase in absorption of the chamber by the total area of pattern. In other words, if the 48 sq.ft. of felt were scattered over 150 sq.ft. of floor area, the absorption per sq.ft. of pattern area would be slightly less than one-third of the coefficient per sq.ft. of felt.

The question naturally arises as to what pattern is the most efficient —in other words, how to obtain the most absorption from a given area of felt. The answer to this lies in the discussion above—the smallest practical area and the widest practical spacing, so long as the spacing does not exceed the maximum effective width. Except on very rare

V



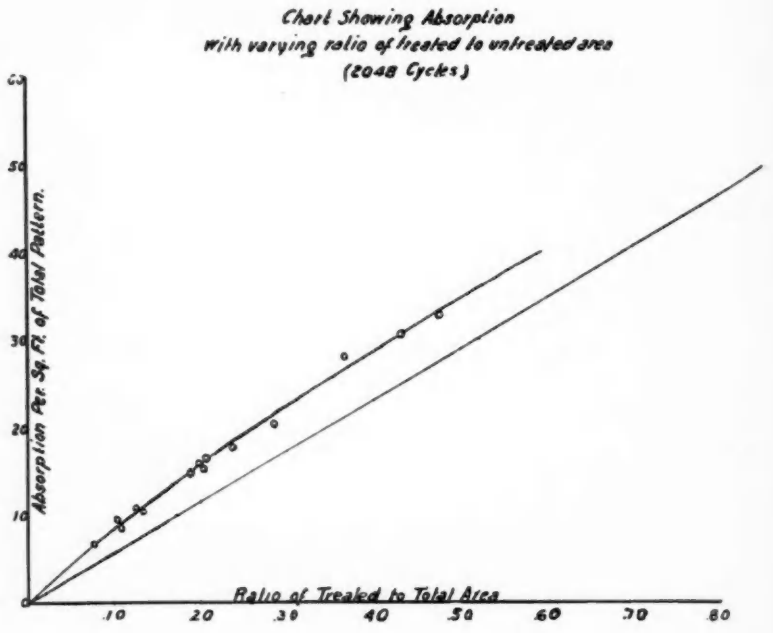
occasions this wastes more area than is desirable. The problem then becomes a question of how to get a certain desired absorption from a given area available for treatment. Assuming that this area is larger than would be required if the necessary absorption were installed in a solid mass, we wish to investigate what pattern arrangement is most efficient. A somewhat surprising fact then comes to light. This fact is shown on Charts #4, #5, and #6. Given a certain ratio of treated to total pattern area it *makes no difference* what pattern arrangement is used. Samples whose dimensions varied from 1′ square to 2′×8′ with spacing from 1 to 4′ were employed in the various tests. Yet the results of these

tests in terms of the absorption per sq.ft. of total pattern are plotted on this graph indiscriminately, and it will be seen that the points fall very nearly on a single curve.

The above charts give values for only three frequencies—512, 1024 and 2048 cycles. Tests were also made at 128 and 256 cycles, but as has been mentioned before, spacing produced no change at these frequencies. The values obtained at 4096 cycles are not plotted because it was felt they were not sufficiently accurate.

The general basis of fact behind this result is probably as follows.

VI



We are limited to a certain maximum area to work with, and we are limited likewise to a certain minimum absorption to be obtained. This gives us a certain necessary absorption per sq.ft. of total pattern, which applied to the chart shows a certain necessary ratio of treated to untreated area. This means that if the individual units of treatment are small the spacing must be small, and similarly if the units are large the spacing must be also. Now we have shown that the absorption is inversely proportional to the area of the unit, and directly proportional to the spacing. Apparently these two factors exactly counterbalance one another in the final result.

Taking a specific example, suppose that the available area in a certain auditorium—the ceiling perhaps—was 1000 sq.ft. And suppose that the necessary absorption was 300 units. This gives a necessary absorption for the entire pattern of 30%. Referring to the chart we find that to achieve this degree of efficiency we must have a ratio of treated to untreated area of 35.7%. In other words, there must be 357 sq.ft. of 1″ felt installed. If it were desired to use less material more absorption per sq. ft. of material would be necessary. This would involve wider spacing and there would not be sufficient room. More material, on the other hand, would require less spacing, but then the total surface area would not be used.

It will be remembered that these results apply only to 1″ Akoustikos Felt. Unquestionably, the curve would have a different slope if the material in question were of a different character. Likewise the tests conducted were confined to dimensions which were considered of practical interest; namely, 1 to 4′. It is possible that very narrow spacings or very narrow strips of material might produce a variation from the general relation, although the present data do not indicate it.

It will be observed that the increase in absorption at any given frequency is directly proportional to the absorption at that frequency. This appears to be true for the same material at different frequencies, but is not true for different materials.

Included in the above charts are values obtained on regular diamonds and hexagons with 2′ spacing. The fact that these points likewise fall on the curves serves as further proof that the arrangement or the spacing does not in itself have a bearing on the absorption if the ratio of treated to total area remains constant.

Returning for a moment to the behavior of different materials when tried under similar conditions, we find a considerable disparity in the results. Observe the following table (all materials being tested in squares 2′×2′ and spaced 2′ apart).

	128	256	512	1024	2048	4096
1″ A A Felt	.07	.30	.78	.96	.78	.48
2″ A A Felt	.19	.74	1.07	1.10	.79	.86
1″ Sanacoustic Tile & Rock Wool	.18	.46	1.11	1.19	1.00	.83 (edges uncovered)
1″ Sanacoustic Tile & Felt	.11	.28	.78	1.03	.88	.75
2″ Rock Cork	.25	.70	1.02	1.04	.80	.74
1″ Nashkote A	.13	.37	.94	.97	.68	.53

If we plot the increase in absorption instead of the actual coefficient obtained we have:

	128	256	512	1024	2048	4096
1″ A A Felt	−.04	−.01	.19	.28	.20	.02
2″ A A Felt	−.02	.28	.28	.35	.21	.40
1″ Sanacoustic Tile & Rock Wool	.05	−.02	.37	.41	.40	.35
1″ Sanacoustic Tile & Felt	.0	−.03	.19	.35	.30	.29
2″ Rock Cork	−.05	.07	.12	.14	.08	.15
1″ Nashkote A	.0	.01	.17	.19	−.05	.07

A certain proportional relationship might be deduced from the results on 1″ and 2″ A A Felt, if we exclude 256 and 4096 cycles. The relationship would be based on a similar percentage increase in the absorption. Any such relationship fails, however, on the samples tested in the tile and is still farther from the truth for the 2″ Rock Cork and Nashkote A tests. These last two, although they show the highest natural absorption of any of the materials are affected to a relatively small degree by spacing. In as much as all of the other variables in the test have been kept constant in these comparisons,—shape, spacing, arrangement, etc.—it seems obvious that there is something in the characteristics of the materials themselves which affects the results. It is for this reason more than any other that the experiments were discontinued. It was obvious that a new research into the mechanics of the absorption of these various materials had become necessary before the data could be made complete.

No claim is made that the work is complete. It is felt that these tests have uncovered a number of rather interesting facts, and that the relationships indicated in the charts above may be of use in predicting the acoustical characteristics of rooms. There is need for further work, however, to extend the data to include both wider and narrower spacings, to include a greater variety of materials and of sample shapes. It seems not beyond the bounds of possibility that if sufficient data were available the results could be combined into a formula which would contain all the variable factors and which would enable the acoustical engineer to predict exactly what a certain arrangement of treatment would accomplish. Before this can be done, however, the scope of the work would have to be widened and more attention will have to be given the underlying theory.

RECENT ADVANCES IN SOUND ABSORPTION MEASUREMENTS

By V. L. Chrisler and W. F. Snyder
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Part I

In a paper given at the last meeting of the Society a method was described by which sound absorption could be determined by oscillograph records. This method was somewhat uncertain and required a large number of records to be taken as the sound does not decay uniformly. Fig. 1 shows the worst conditions and Fig. 2 one of the best. At any given point two things may be taking place: the sound is decaying and there may be a drift of the sound pattern. It seemed that

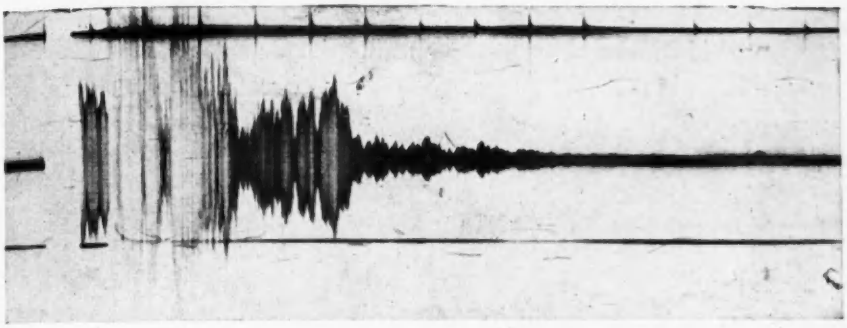

Fig. 1. *Oscillogram of Sound Decay.*

a large part of the error due to the drift of the sound pattern might be eliminated by obtaining a record in which the sound intensity decayed by some 30 or 40 decibels.

To obtain a record of such a large intensity change it was necessary to change the amount of amplification. This was accomplished by the use of an attenuator in the amplifier circuit. Fig. 3 shows how such a record looks. By drawing envelopes to these two decay curves and then drawing parallel lines as shown we can determine the time that is required for the sound to decay by a definite amount. The amount of thisdecay is known if a calibrated attenuator is used. The absorption can be calculated from the generally accepted formula $a = (k \log I_1 - \log_2 I/)$ $(T_1 - T_2)$ where a is the total absorption, K a constant depending on the dimensions of the room and the velocity of sound, $\log I_1 - \log I_2$ is 1/10 the change in intensity expressed in decibels and determined by the

calibrated attenuator box, and $T_1 - T_2$ the time required for this intensity change.

This gives us a method which is very similar to the reverberation method. The principal difference lies in the fact that we no longer use

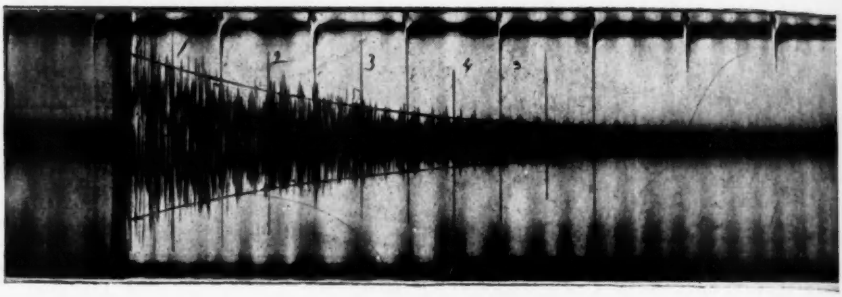

FIG. 2. *Oscillogram of Sound Decay.*

the threshold of audibility but determine the time of decay for a measured change in intensity. A large number of records have been made in this manner, but the results are somewhat disappointing when used to determine absorption coefficients of materials. It was hoped that

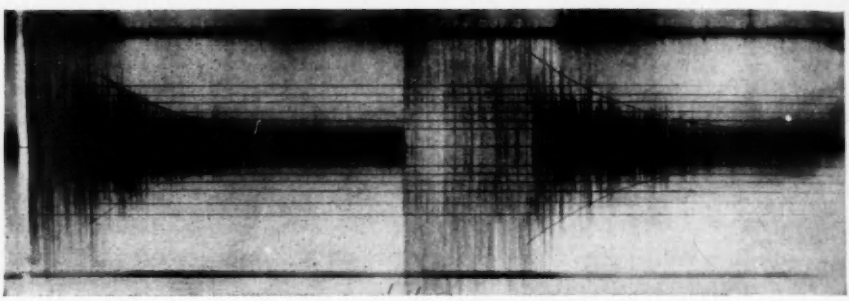

FIG. 3. *Oscillogram of Sound Decay.*

the time of decay of a given sound through a given change of intensity would be constant provided the other conditions remained constant. It was found, however, that this time was not a constant due probably to the drift of the sound pattern. Variations were found corresponding to those obtained by a good observer using a stop watch to measure the reverberation time, but the variations were somewhat smaller in magnitude. Consequently it is necessary to take a number of films and use average values if satisfactory results are to be obtained when measuring the sound absorption coefficient of samples of material. If only the reverberation time were desired a single film might prove sufficient, as the error would probably not be more than 3 percent.

As it is a slow process to take these oscillograph records and work them up, the oscillograph has finally been abandoned and the process slightly modified. The oscillograph method as described consisted essentially in determining the length of time required for a sound to decay by a given amount. This can also be done by substituting a rectifying tube and microammeter.

The measurements can be made much faster in this manner, but the accuracy of determining the time interval by a single measurement is not as great as that obtained from a single film taken with the oscillograph. The time intervals can be determined more accurately, however, than by listening for the end point with the ear alone. To obtain satisfactory results by the rectifying tube and microammeter method it is, then, necessary to make a large number of measurements, the same as by the reverberation method, but it is believed that the accuracy of measurement is somewhat greater than when the ear is used as a measuring instrument.

The results of some of these measurements are given in Table 1.

TABLE I.

Sample	Method	Absorption Coefficients at Frequency					
		128	256	512	1024	2048	4096
No. 1	Instrument	.14	.27	.53	.62	.60	.54
	Oscillograph	.16	.30	.53	.63	—	—
	Ear	.16	.28	.52	.66	.58	.42
No. 2	Instrument	.08	.13	.25	.54	.67	.42
	Ear	.10	.14	.24	.55	.67	.40
No. 3	Instrument	.19	.34	.63	.75	.77	.52
	Ear	.17	.31	.62	.75	.76	.44

PART II

As there have been no recent measurements on the sound absorption of an audience it was thought that it would be worth while to repeat some of these measurements.

A woman wears considerably less clothing than she did 20 years ago, hence it is to be expected that the average absorption of an audience will be somewhat smaller than it was at that time. Also the absorption of an audience should vary considerably between winter

and summer. With this in mind we have made a number of absorption measurements under different audience conditions.

The results are shown in the following curves. Fig. 4 shows the absorption which was obtained when an audience was seated in open back chairs; practically all of the clothing being effective in producing sound absorption. The chairs were spaced rather far apart to obtain the total absorption of each person. It will be noticed that the absorption of a woman without a coat is far below the usually accepted value. A man

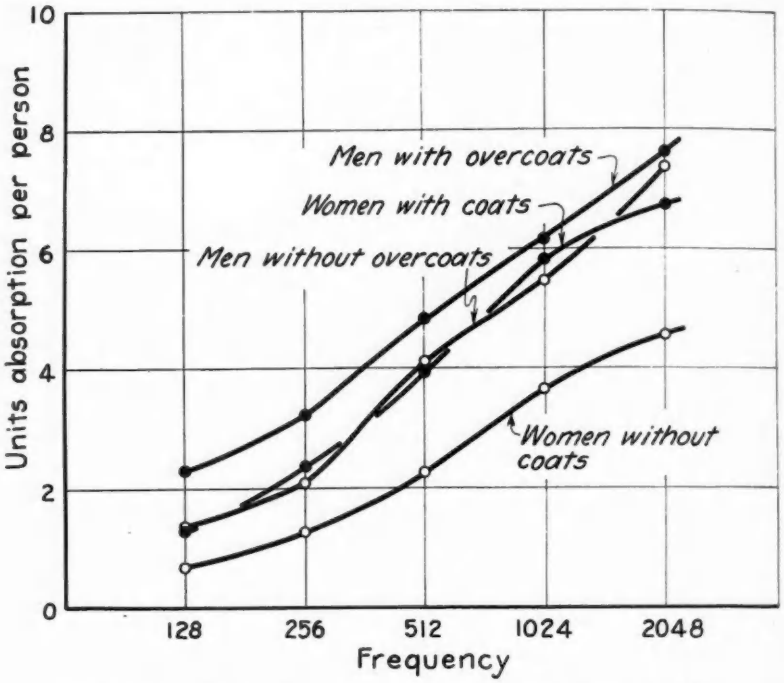

FIG. 4. *Curves showing absorption of audience under different conditions.*

with an overcoat which he is not wearing has approximately the absorption which is usually accepted. In each test there were 15 men or 15 women, which should give a fair average although a larger audience would have been better in this respect. From the standpoint of noise, however, there were too many people for it was rather difficult for that number of persons to keep still while the measurements were taken.

Other measurements were made with a mixed audience of 6 men and 6 women seated in different kinds of seats. The results of the measurements are shown in Figs. 5 and 6. The most interesting

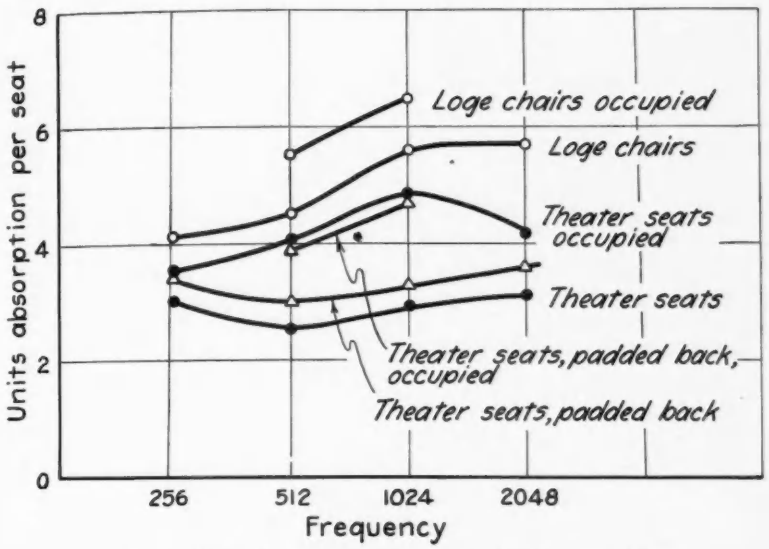

FIG. 5. *Absorption of theatre seats occupied and unoccupied.*

feature of these curves is the change in absorption owing to the seats being occupied. For the upholstered pews it will be noticed that this change is 1½ to 2 units per person while in a well padded theatre seat it is approximately 1 unit. No measurements were made with an au-

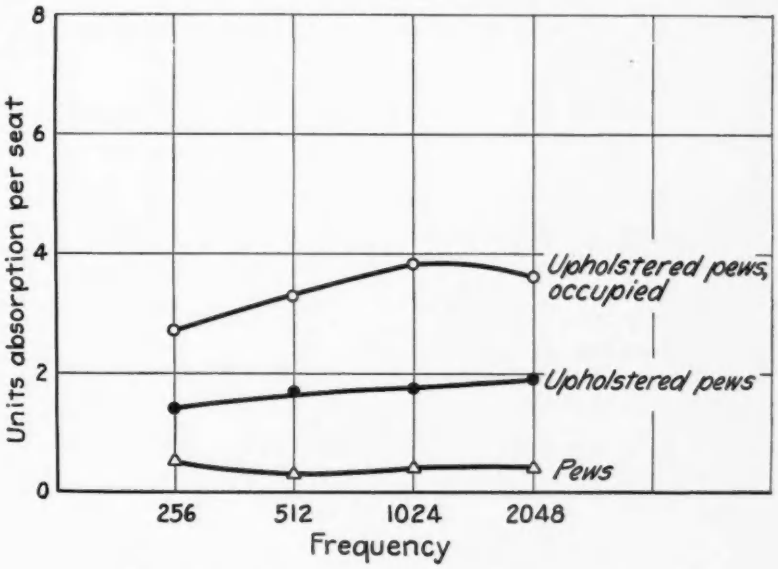

FIG. 6. *Absorption of church pews occupied and unoccupied.*

dience seated in unupholstered pews, but as the upholstery was almost completely covered it is probable that the absorption would be practically the same as for upholstered pews. In this case the change in absorption due to the pew being occupied would be about 3 units.

As the audience is the most important factor in determining the total absorption of an auditorium it is suggested that other observers should make measurements of this type and a new value be established for the average absorption of a person.

MEASUREMENT AND CALCULATION OF SOUND-INSULATION

By Vern O. Knudsen
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They are many apparent discrepancies among the published data on sound-insulation. These discrepancies may not be real but they are none-the-less responsible for a great deal of unfortunate, and unnecessary, confusion among architects, builders, and even acoustical engineers. In the absence of satisfactory data, the inquirer may have doubts concerning the reliability of all published data on sound-insulation.

It has been shown by Buckingham[1] and also by Davis[2] that the insulative properties of panels which are ordinarily measured by different methods, or even by the same method in different laboratories, are not of such a nature as will admit of a direct comparison. Both Buckingham and Davis have made critical studies of the methods currently used; have derived formulas, and suggested experimental methods, for determining the sound-insulation of panels; and have suggested that the result of all measurements be given in terms of the fractional amount of the incident sound energy the panel will transmit (coefficient of transmission), rather than in terms of the intensities of the sound on both sides of the panel—intensities which will depend upon the size of the panel and the acoustical properties of the test room as well as the transmitting properties of the panel.

Much of the existing confusion probably would have been avoided if the same term, namely "reduction factor," had not been used with different meanings. Thus, P. E. Sabine[3] defines the "reduction factor" as the ratio of the intensity of the sound on the source side of the panel to the intensity on the opposite side, when this latter intensity is just barely audible in quiet surroundings. The Bureau of Standards[4] and

[1] Edgar Buckingham, Theory and Interpretation of Experiments on the Transmission of Sound through Partition Walls, Bureau of Standards Scientific Paper, No. 506, 193, (1925).

[2] A. H. Davis, Reverberation Equations for Two Adjacent Rooms Connected by an Incompletely Soundproof Partition, Phil. Mag., 50, 75, (1925); The Basis of Acoustic Measurements by Reverberation Methods, Phil. Mag. 2, 543, (1926).

[3] Paul E. Sabine, Transmission of Sound by Walls, Jour. Acous. Soc., 1, 182, (Jan., 1930).

[4] V. L. Chrisler and W. F. Snyder, Transmission of Sound through Wall and Floor Structures, Bureau of Standards, Research Paper, No. 42, 541, (1929). See also E. A. Eckhardt and V. L. Chrisler, Transmission and Absorption of Sound by Some Building Materials, Bureau of Standards Scientific Paper, No. 526, 37, (1926).

the National Physical Laboratories[5] define the "reduction factor" as the reciprocal of the coefficient of transmission of the panel. Obviously, these two definitions of "reduction factor" are different, and it is not surprising therefore that the results from the Riverbank Laboratories and from the Bureau of Standards are not in apparent agreement.

In the present paper the coefficient of transmission, as defined, and designated by τ, will be used to describe the insulative properties of a material or type of construction. It will be shown later that these coefficients are in a convenient form for calculating the over-all or effective insulation furnished by the boundaries of a room. However, for many purposes it is desirable to describe the insulation value of materials or structures in terms of the reciprocal of the coefficient of transmission, which gives a measure of the attenuation of the sound transmitted through the panel. Further, following the custom of telephone and acoustical engineers, it often is desirable to convert this attenuation into the transmission loss in decibels. Hence the transmission loss in decibels, designated by T. L., for a particular panel will be given by

$$T.L. = 10 \log_{10} \frac{1}{\tau} \cdot \tag{1}$$

The term "reduction factor," following essentially the definition given by P. E. Sabine, seems to be a suitable term for evaluating the effective or over-all insulation of a room, that is the ratio of the intensity of sound outside of the room to the intensity of the sound which is transmitted into the room.

Following the theoretical considerations of Buckingham,[6] it is a simple matter to obtain equations for determining the coefficients of transmission of a panel by any one of several experimental methods. Three typical methods, which are commonly used at the Bureau of Standards, at the Riverbank Laboratories and elsewhere, will be considered. In all three methods it will be assumed that the panel under test is large enough, and secured around its edges in such a manner, that the panel will vibrate and transmit sound energy approximately as it would in an actual building structure. In general, this assumption is reasonably valid for masonry panels and for wood stud and plaster

[5] A. H. Davis and T. S. Littler, The Measurement of Transmission and Reflection of Sound by Partitions of Various Materials.—I. Felt-Like Materials, Phil. Mag. 3, 177, (1927), The Transmission of Sound through Partitions.—II. Vibrating Partitions, Phil. Mag. 7; 1050, (1929).

[6] Loc. cit.

panels which are larger than $3' \times 5'$.[7] In all three methods it is assumed that the test panel closes an aperture between two rooms—a source room and a test room—and that no sound energy is transmitted from the source room to the test room except through the test panel. It also is assumed that the coefficients of transmission are independent of the intensity of the sound. This is not strictly true, but is approximately so. Finally, it is assumed that the sound energy in both the source room and the test room is thoroughly mixed, so that the effects of interference and non-uniform distribution will be negligible. The three methods which will be considered are as follows:

1. Measurement of the intensities of sound in the source room and in the test room. It is possible to make intensity measurements in both rooms by methods similar to those used at the Bureau of Standards;[8] or by reducing the intensities in the source room to the minimal threshold of audibility first when an observer listens in the source room, and then when the same observer listens in the test room;[9] or by other methods.[10] Let I_1 be the average intensity in the source room, I_2 the average intensity in the test room, A the area of the test panel, a_2 the total amount of absorption in the test room, and v the velocity of sound. Then the rate of flow of sound energy against the panel in the source room will be $(I_1 v/4)A$; and the rate at which sound energy will be transmitted through the panel will be $(I_1 v/4)A\tau$. Hence, $(I_1 v/4)A\tau$ is the rate of emission of sound energy in the test room, which will be designated by E_2. But

$$I_2 = \frac{4E_2}{va_2} = \frac{4I_1 vA\tau}{va_2 4},$$

whence,

$$\tau = \frac{a_2 I_2}{AI_1}. \qquad (2)$$

Therefore, in order to determine the coefficient of transmission of a panel by this method it is necessary to know the total absorption in the test room and the area of the test panel, as well as the intensities on both sides of the panel.

[7] The writer has made laboratory tests on panels $3' \times 5'$; field tests on small rooms, $8' \times 10' \times 8'$, made of the same materials; and field tests on large rooms, $100' \times 150' \times 40'$, made of the same materials; and in all cases the T.L. did not differ by more than 4 or 5 db.

[8] Loc. cit.

[9] This method requires that the rooms be utterly free from all outside noise.

[10] See, for example, method used by W. Waterfall, Jour. Acous. Soc. 1, 209, in which the masking effect of an audiometer is utilized. This method has the advantage of not requiring complete absence of disturbing noises.

2. Measurement of the intensities of sound in the test room with and without the panel in the aperture. This method is essentially the one used at the Bureau of Standards and at the National Physical Laboratory. The intensities ordinarily are determined by means of a microphone and a suitable amplifier and galvanometer. The apparatus requirements can be simplified by using an electrical attenuator in the input of an electrodynamic loud-speaker, which serves as the source of sound, and by making measurements of minimal audibility in the test room with and without the panel in place. The equations which apply to the minimal audibility method may be derived as follows:

When the panel is in place, the rate of energy flow against the panel will be E_1A/a_1, where E_1 is the rate of energy emission from the source for a tone which is just barely audible in the test room. Then the rate of flow of energy through the panel will be $(E_1A/a_1)\tau$. Hence, if I_m be the minimal threshold intensity in the test room,

$$I_m = \frac{4}{a_2 v} \frac{E_1 A}{a_1} \tau. \tag{3}$$

When the panel is out, the rate of flow of sound energy into the test room at minimal audibility will be $E_1'A/a_1'$, where E_1' is the rate of emission of the source and a_1' is the absorption in the source room with the panel out. Therefore,

$$I_m = \frac{4}{a_2' v} \frac{E_1' A}{a_1'}, \tag{4}$$

where a_2' is the absorption in the test room with the panel out. Equating (3) and (4), and solving for τ,

$$\tau = \frac{E_1'}{E_1} \frac{a_1}{a_1'} \frac{a_2}{a_2'}. \tag{5}$$

If the source and test rooms contain large amounts of sound-absorptive materials, a_1 will not differ much from a_1', and a_2 will not differ much from a_2'. Whence, approximately,

$$\tau = \frac{E_1'}{E_1}. \tag{6}$$

Or, it is possible to add absorptive materials to both rooms when the panel is in, so that $a_1 = a_1'$ and $a_2 = a_2'$, in which case (6) applies directly, and it is not necessary to know the amounts of absorption in the source and test rooms.

When an attenuator is used in the input of the loud-speaker, as described, the ratio E_1'/E_1 is given in terms of the decibels of attenuation introduced in the loud-speaker. Thus, if the difference between the two settings of the attenuator be 30 db, the rates of emission of the source differ one thousand fold, that is E_1'/E_1 would be .001.

3. The reverberation method. This method, devised by W. C. Sabine and developed and used extensively by P. E. Sabine, is a method of comparing the intensities on the two sides of the test panel. The sound in the source room, which should be a very reverberant room, is stopped and allowed to decay. An observer then measures the duration of audibility in the source room (which is designated by t_1) and then measures the duration of audibility in the test room (which is designated by t_2). When the decaying sound in the source room has decayed for t_2 seconds the intensity in the source room is just of sufficient strength to be barely audible in the test room. If the reverberant sound in the test room be negligible in comparison with the direct beam of sound transmitted through the panel, it can be shown easily that

$$\log_e \frac{I_1}{I_2} = \frac{va_1}{4V_1}(t_1 - t_2), \tag{7}$$

where V_1 is the volume of the source room, and the other symbols have the meaning heretofore assigned. Sabine expresses the "reduction factor" of the panel in terms of the I_1/I_2, but it is obvious that this quantity cannot be directly compared with the $1/\tau$ determined by the two methods just considered. However, the τ can be determined approximately from Sabine's data by the relation

$$\tau = \frac{a_2 I_2}{A I_1}, \tag{2}$$

provided the reverberant sound in the test room be small compared with the transmitted beam.

Buckingham has derived a more rigorous equation, based upon reverberation measurements, which does not neglect the effect of the reverberation in the test room, and which therefore leads to a more exact method for determining τ. Buckingham assumes that the rate of decay of sound in the test room is the difference between the rate of absorption of energy by the boundaries and contents of the test room and the rate of supply of energy transmitted through the panel. Starting with this very reasonable assumption, and introducing a second assumption, namely that the amount of energy transmitted from the test room back

into the source room is small, which also is plausible, especially for panels which have a low transmittance, he obtains the following equation:

$$\tau = \frac{a_2}{A} \frac{(b_1 - b_2)e^{-b_1 t_1}}{b_1 e^{-b_2 t_2} - b_2 e^{-b_1 t_2}}, \tag{8}$$

where $b_1 = va_1/4V_1$, (a_1 = total absorption; V_1 = volume of source room) and $b_2 = va_2/4V_2$, (a_2 = total absorption; V_2 = volume of test room).[11] If b_2 be rather large compared with b_1 (as it is in the Riverbank Laboratories and the Acoustical Laboratory at the University of California at Los Angeles) then (8) reduces to

$$\tau = \frac{a_2}{A} \frac{(b_2 - b_1)}{b_2} e^{-b_1(t_1 - t_2)}. \tag{9}$$

The writer has subjected this last equation to experimental test, and finds that the coefficients of transmission obtained by the reverberation method, using this equation, are in substantial agreement with the coefficients obtained by the other two methods described in this paper.

The plan of the acoustical laboratory where the tests were conducted, and also the general arrangement of the apparatus, are indicated in Fig. 1. The walls of the reverberation (or source) room and the test rooms are made of two twelve inch reinforced concrete walls separated by twelve inch air spaces, similar to the construction used in the Riverbank Laboratories. All three rooms are further insulated from each other, from the ground, and from the main structure of the Physics Building, by means of a two inch layer of corkboard under the concrete slab of each room, as shown in Fig. 2. The cork loaded with the concrete room that it supports has a natural frequency of about 10 d.v. so that all frequencies above 20 d.v. are effectively prevented from reaching these rooms through the floors. The panels to be tested are securely clamped and sealed in an opening, $3' \times 5'$, between the source and test rooms.

The results of tests, by the three different methods, on two typical panels are given in Table 1. The one panel was a $\frac{1}{2}''$ mineral wool blanket covered on both sides with a heavy grade of wrapping paper; the other panel was $\frac{1}{2}''$ plaster board. Tests were made at frequencies of 128 d.v., 512 d.v. and 2048 d.v., and the intensities in both the source and test rooms were determined by introducing sufficient attenuation

[11] If either source or test room be non-reverberant, it is necessary to set $a_1 = -s_1 \log_e (1-\alpha_1)$, and $a_2 = -s_2 \log_e (1-\alpha_2)$, where s is the interior surface and α the average coefficient of absorption for each room. (See Eyring, "Reverberation in Dead Rooms," Jour. Acous. Soc., Jan., 1930.)

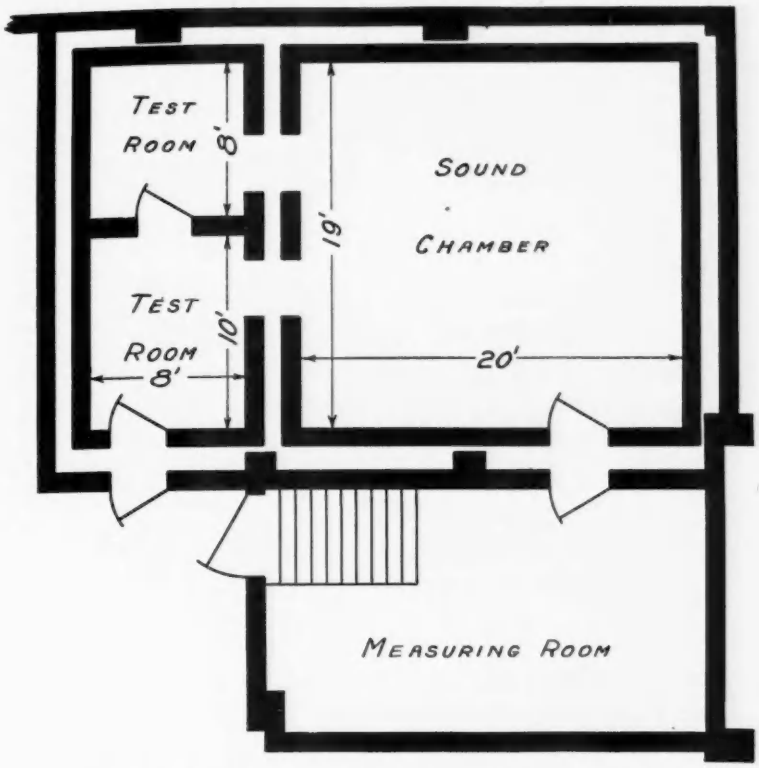

FIG. 1. *Plan of the Acoustical Laboratory of the University of California at Los Angeles.*

TABLE I

	Method 1. Intensity on both sides of the panel.	Method 2. Intensity with and without panel in place.	Method 3. Reverberation measurements.	Average of the three methods.
(½" Mineral Wool Blanket)				
T.L. (128 d.v.)	12.8 db	11.4 db	13.0 db	12.4 db
T.L. (512 d.v.)	15.2 "	14.2 "	15.7 "	15.0 "
T.L. (2048 d.v.)	18.7 "	18.8 "	20.3 "	19.3 "
T.L. (average)	15.6 "	14.8 "	16.3 "	15.6 "
τ (average)	.028	.033	.024	.028
(½" Plaster Board)				
T.L. (128 d.v.)	26.9 db	26.7 db	27.3 db	27.0 db
T.L. (512 d.v.)	27.6 "	28.8 "	27.5 "	28.0 "
T.L. (2048 d.v.)	32.7 "	32.7 "	33.6 "	33.0 "
T.L. (average)	29.1 "	29.4 "	29.5 "	29.3 "
τ (average)	.0012	.00115	.0011	.00116

in the attenuator to reduce the test tones to the minimal threshold of audibility. During these measurements, the loud-speaker was swinging as a simple pendulum so that the effects of interference were minimized. The results are given in terms of the T. L. at each frequency, the average T. L. for the three frequencies, and the average value of the coefficient of transmission. (In all cases, the arithmetical mean is taken as the average value.)

As will be noted, the results obtained by the three different methods of measurement are in good agreement. The differences are no larger than the errors of measurement of minimal audibility, namely about 1 db.

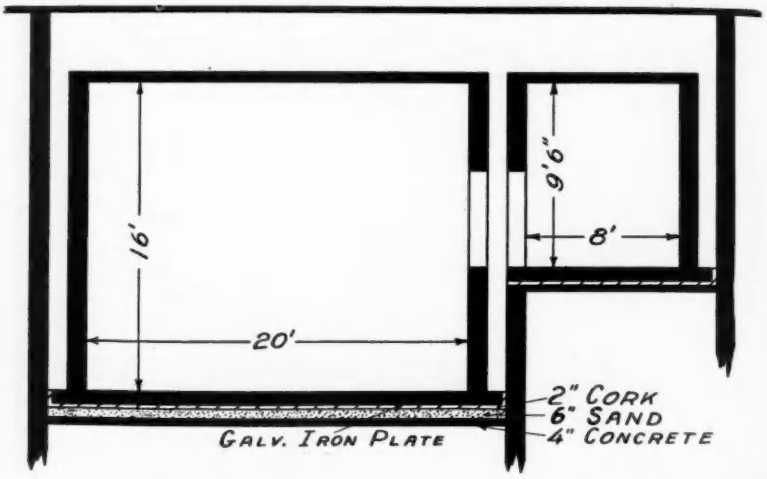

FIG. 2. *Cross section through Acoustical Laboratory, showing (a) how the sound chamber is insulated from the solid structure of the building, and (b) the arrangement of the sound chamber and test rooms.*

The good agreement obtained by these different methods would seem to indicate that the results from the Riverbank Laboratories and from the Bureau of Standards should be in essential agreement provided the results from both laboratories be converted into quantities which specify only the transmitting properties of the panel. The published results of the Bureau of Standards on sound-insulation are given, at least very approximately, in terms of what has been defined in this paper as the transmission loss in decibels (T.L.). By means of equations (7) and (9) it is possible to convert Sabine's results into corresponding values of τ or T. L.

The author has attempted to translate Sabine's data on rigid parti-

tions, such as tile and plaster partitions, into corresponding values of T.L. so that they may be compared with Chrisler's and Snyder's values of T. L. for rigid partitions. Rigid partitions were chosen for the purpose of comparison because it would seem that they should be more nearly alike at the two laboratories than other types of partition. One or two estimations were made concerning the volume of the test room and the amount of absorption in it, but for the most part complete data were available in Sabine's publications so that it is probable that the calculations of the T. L. are not in error by more than one or two decibels. A typical calculation will be worked through for a panel having a "reduction factor" (as defined and reported by Sabine) of 40 db at 512 d.v.

$V_1 = 10{,}200$ cu. ft., $t_1 = 14.36$ sec., $a_1 = 49.5$, $b_1 = 1.33$.
$V_2 = 550$ cu. ft., $a_2 = 13.2$, $b_2 = 6.71$, $A = 50$ sq. ft.
From (7), $t_1 - t_2 = 40/5.78 = 6.93$,
hence from (9), $\tau = (13.2/50 \cdot 5.38/6.71)e^{-1.33 \times 6.93} = .0000213$,
and T. L. $= 10 \log_{10} 1/\tau = 46.7$ db.

It appears, therefore, that a reduction of 40 db, as given in Sabine's data for a test tone of 512 d.v., would correspond to a transmission loss (T.L.) of 46.7 db. That is, in this instance, it is necessary to add 6.7 db to Sabine's "reduction factor" in order to convert it into T. L. Further, this same addition of approximately 6.7 db should be made to all of Sabine's "reduction factors" at 512 d.v. in order to convert them into T. L.[12] Similarly, on the basis of such estimations and calculations for test tones of other frequencies, it appears that it is necessary to add approximately 7.3 db at 128 d.v. and 4.5 db at 2048 d.v. in order to convert Sabine's "reduction factors" into T. L., that is, into results which should be comparable with the results of the Bureau of Standards or the National Physical Laboratory. In fact, it will be found that these additions to Sabine's "reduction factors" will make his results on rigid partitions, such as tile and plaster or brick and plaster, in reasonably good agreement with Chrisler's and Snyder's results on similar partitions. The nature of this agreement is indicated by the data in Tables II and III which give the calculated values of T. L. for a number of comparable panels which have been tested at either the Riverbank Laboratories or the Bureau of Standards. Types of rigid panel were selected for comparison which were as nearly alike as could be found

[12] Provided, of course, that the panel does not alter appreciably the amounts of absorption in the test and source rooms.

in the published data of Sabine and Chrisler, and they cover a range of rigid panels from $\frac{1}{4}''$ plate glass to an 8″ brick wall. The calculated values of T. L. are restricted to the frequency range of 256 d.v. to 2048 d.v.—about the extent of the range which is common to the data from both laboratories. It will be noted that, although there are rather large discrepancies between individual results from the two laboratories, the mean results for panels which are nearly alike are in as good agreement as reasonably could be expected. The mean T.L.'s in these two Tables are plotted, in the usual manner, in Fig. 3. The results from Sa-

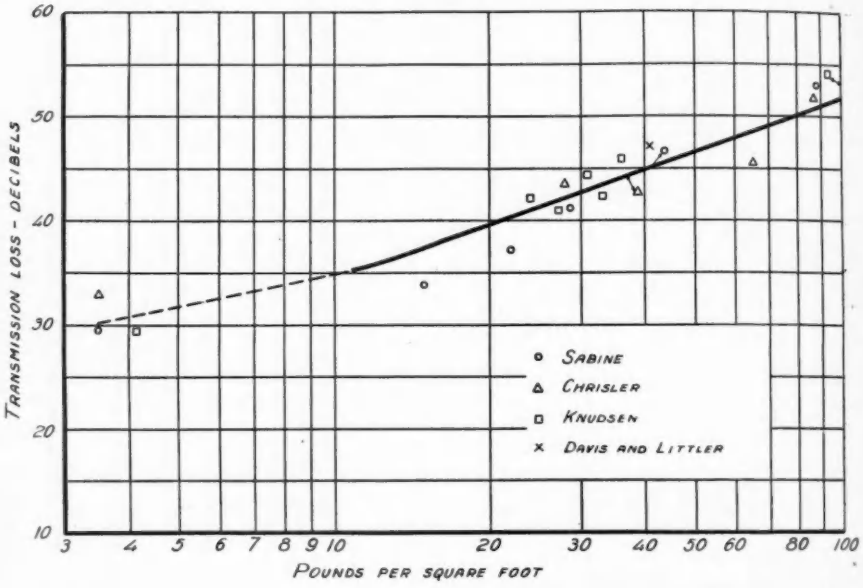

FIG. 3. *Curve showing a summary of transmission loss measurements obtained by different observers for rigid partitions. The transmission loss in decibels is plotted against the mass per square foot of the wall section. The partitions tested varied from $\frac{1}{4}''$ plate glass to plastered 8″ brick walls.*

bine's data are indicated by small circles, and the results from Chrisler's data by small triangles. In addition, similar mean T. L.'s. from tests conducted by the author on plate glass, clay tile and plaster, gypsum tile and plaster, and brick and plaster partitions, are indicated in Fig. 3 by small squares. Finally, the mean T. L. for a brick wall tested by Davis and Littler is shown in Fig. 3 by a small cross. It would seem therefore that insulation data, at least for rigid partitions, from all four laboratories are in good accord, and that the curve drawn through the experimental points in Fig. 3 gives at least a close approximation to

the actual T. L. supplied by rigid partitions of different weights per square foot of wall section.

TABLE II

VALUES OF T.L. CALCULATED FROM SABINE'S DATA

Material	Weight per sq. ft.	256 d.v.	512 d.v.	1024 d.v.	2048 d.v.	Mean Value	τ (average)
$\frac{1}{4}''$ plate glass		29.0	31.7	30.8	27.0	29.6	.0011
2″ solid gypsum tile and $\frac{1}{2}''$ plaster	15.0	28.3	31.7	36.7	38.0	33.7	.00043
4″ clay tile and $\frac{1}{2}''$ plaster	22.0	31.5	33.8	44.0	39.0	37.1	.000195
4″ clay tile and $1\frac{1}{4}''$ plaster	28.6	35.5	37.8	46.0	45.0	41.1	.000078
$4\frac{1}{2}''$ plaster on metal lath	41.8	37.0	42.7	50.7	50.0	45.1	.000031
8″ brick wall, 1″ plaster	88.0					52.8	.0000052

TABLE III

VALUES OF T.L. CALCULATED FROM CHRISLER'S AND SNYDER'S DATA

Material	Weight per sq. ft.	256 d.v.	512 d.v.	1024 d.v.	2048 d.v.	Mean Value	τ (average)
$\frac{1}{4}''$ plate glass	3.5	32.6	30.9	33.5	34.2	32.8	.00053
3″ clay tile and plaster	28.0	41.2	38.6	43.5	50.4	43.4	.000046
6″ clay tile and plaster	37.0	41.2	37.4	45.1	52.1	43.9	.000041
12″ clay tile and plaster	65.0	49.4	40.1	37.0	55.2	45.4	.000029
8″ brick wall and plaster	87.0	50.2	47.6	55.5	53.9	51.8	.0000066

A simple consideration of the manner in which eqn. (2) was derived will lead to a very useful equation for calculating the effective insulation against air-borne sound supplied by any room or building. Thus, suppose a room is located where the intensity of the outside noise is I_1. Then the rate at which sound energy strikes unit area of the outside boundaries of this room is $I_1 v/4$. Now, suppose that A_1 square feet of the material or structure which encloses the room have a coefficient of transmission of τ_1, A_2 square feet a coefficient of transmission of τ_2, A_3 square feet a coefficient of transmission of τ_3, etc. Then the total sound energy transmitted through the entire boundaries of the room will be

$$\frac{I_1 v}{4}(A_1\tau_1 + A_2\tau_2 + A_3\tau_3 + \cdots), \tag{10}$$

where $A_1+A_2+A_3+\cdots$ will be the entire surface boundary through which the outside sound may be transmitted into the room. Hence, if the total absorption inside the room be a_2, the intensity I_2 of the sound which has been transmitted into the room will be

$$I_2 = \frac{4}{a_2 v}\,\frac{I_1 v}{4}(A_1\tau_1 + A_2\tau_2 + A_3\tau_3 + \cdots),$$

or

$$I_2 = \frac{I_1}{a_2}T, \tag{11}$$

where $T = A_1\tau_1 + A_2\tau_2 + A_3\tau_3 + \cdots = \Sigma A\tau$. T then is the total transmission through the entire boundaries of the room. Therefore, the ratio of the intensity of the sound outside of the room to the intensity of the sound which has been transmitted into the room is

$$\frac{I_1}{I_2} = \frac{a_2}{T}, \tag{12}$$

and the reduction factor in decibels is

$$\text{Reduction factor} = 10 \log_{10} \frac{a_2}{T} \text{decibels.} \tag{13}$$

Eqn. (13) gives the effective insulation supplied by a room, and, as would be anticipated, the energy reduction of the transmitted sound is proportional directly to the total absorption in the room and inversely to the total transmission into the room. In order to illustrate the use of this equation in the design of rooms, suppose it is desired to know how much insulation will be provided by a wall of a room which faces say a noisy street. Suppose the exterior wall of the room to be made up of 200 sq. ft. of 8″ brick, plastered on the inside, and 40 sq. ft of ¼″ glass windows; and suppose further that the total absorption in the room be 250 sq. ft. units. Then, using the average values of τ for ¼″ glass and 8″ brick as given in Tables II and III,

$$T = 200 \times .0000059 + 40 \times .00081 = .0336$$

$\therefore$ Reduction factor $= 10 \log_{10} 250/.0336 = 38.7$ db.

Hence, if the outside street noise be 70 db, it will be reduced to 31.3 db inside of the room. If 20 sq. ft. of the windows be opened, neglecting diffraction around the window openings,

$$T = 200 \times .0000059 + 20 \times .00081 + 20 \times 1.0 = 20.01,$$

or the reduction factor would then be only 11.0 db. On the other hand, if there were no windows so that the entire wall were an 8″ brick wall, the reduction factor would be 52.5 db. There are numerous other uses of eqn. (13), such as determining the insulation supplied by existing buildings, or designing rooms or buildings which must have a specified amount of sound-insulation.